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NOTE ON THE ATMOSPHERIC BANDS IN THE SPECTRUM OF MARS.

By WILLIAM HUGGINS.

THE question of any part of the bands seen by me in 1862–1867 in the spectrum of Mars being really due to the planet's atmosphere having been raised by the recent observations of Professor Campbell, we have taken the opportunity of Mars and the Moon being visible together on the same nights to repeat my early observations.

The method employed by me in 1867 to eliminate the effect of the absorption of our own atmosphere from the planet's spectrum was to compare with it on the same night the spectrum of the Moon when at a similar or lower altitude (*M. N.* **27**, 178). In my later work on the planets by photography, in 1879, another plan was adopted, namely, to take the photographs when the twilight was just strong enough to give upon the plate the spectrum of the sky close about the planet, without enfeebling too much that of the planet itself (*Phil. Trans.* 1880, p. 687).

On November 8, 1894, six photographs of the Moon's spectrum and four of the spectrum of Mars were taken with different exposures, giving a range of spectrum from F to S in the

ultra-violet. They were afterwards compared by placing a Mars' spectrum upon a Moon's spectrum, but in accordance with my photographs of 1879 no bands, or other modification of the lunar spectrum strong enough to be detected in the photographs, could be discovered as peculiar to the planet's spectrum.

On November 8, 10, and 15 we compared by eye the spectrum of Mars with that of the Moon, and observations of the spectrum of Mars when near the meridian were made on December 15, 18, and 20. Great care and caution are necessary in attempting to estimate the relative intensities of faint bands in the spectra of objects so different as Mars and the Moon, and which, though they can be observed within a few minutes of each other, cannot be viewed simultaneously. As the judgment of the eye is influenced by brightness and breadth of spectrum, care was taken to make the lunar spectrum as narrow and about as bright as that of Mars. On these three nights the atmospheric bands on both sides of D, to which our attention was almost exclusively directed, varied considerably in intensity in the Moon's spectrum, but were always estimated by us to be rather stronger in the spectrum of Mars. The particular terrestrial groups on which our estimations were chiefly based are the narrow band from λ 5928 to about λ 5935 and the stronger group nearer D at about λ 5910–5925. We strongly suspected that the broad atmospheric group which includes D, and extends from about λ 5885 to λ 5905, was rather more distinct in the spectrum of Mars, the Moon having a lower altitude at the time.

These comparisons were repeated several times on each night, and Mrs. Huggins' independent observations agreed with my own that the bands I have named were always rather more easily seen in the planet's spectrum than in that of the Moon, even when at a lower altitude.

Though we reserve our final opinion as to whether there are any Martian bands which do not correspond with those of our own atmosphere, we think it well to put on record that we have little doubt of the existence of a band on the blue side of D, beginning at the stronger end at about λ 5860, and traceable to

beyond λ 5840, which does not appear to be the same as any terrestrial group, and may, therefore, presumably be peculiar to the atmosphere of Mars. We took pains to be quite sure that we were not deceived by the solar lines at that place in the spectrum, which, indeed, are quite different in their relative arrangement. The visibility of this band is subject to great variation, depending, it may be, on the state of the planet's atmosphere. It was distinctly seen on November 10.

A long series of cloudy nights has unfortunately prevented us from making our observations more complete, but we think it undesirable to delay longer in stating that the result of our work is to leave a strong conviction in our minds that the spectroscope does show an absorption which is really due to the atmosphere of Mars.

LONDON, January 6, 1895.

RECENT RESEARCHES ON THE SPECTRA OF THE PLANETS. I.[1]

By H. C. Vogel.

The results which were obtained by the first observers who undertook the investigation of the spectra of the planets were very contradictory, partly on account of the faintness of the spectra, and partly on account of imperfect apparatus. In the beginning of the year 1870 I endeavored to throw some light on this department of celestial spectroscopy; by my own observations, in the first place, and in the second place by a careful and critical comparison of such observations as had already been made. My memoir entitled "Untersuchungen über die Spectra der Planeten," which had been awarded a prize by the Scientific Society of Copenhagen, appeared in print in the year 1874.[2] Thanks to the excellent instruments which were at my disposal in the private observatory of Herr von Bülow, and to the extreme sensitiveness of my eye, I was able to see and to measure so many details in the spectra of the principal planets that no observations really subverting my results were to be expected in the future. As a matter of fact, neither the great instruments of modern times, nor the application of photography — so powerful in the field of celestial spectroscopy — has done more in this direction than to confirm the results of these early observations.

At first sight this seems to be a surprising fact; it is, however, founded in the nature of the circumstances, as I will proceed to show here in a somewhat detailed manner.

In the case of most of the larger planets the image in the focal plane of a telescope is a surface of considerable diameter, only a small strip of which is cut out by the jaws of the slit. With a constant ratio of focal length to aperture, the intensity of the image, and therefore the brightness of the spectrum, is

[1] Communicated to the Royal Prussian Academy of Sciences; translated from an advance proof of the *Sitzungsberichte* sent by the author.

[2] Leipzig, W. Engelmann.

nearly the same for all sizes of telescopes. It is, indeed, somewhat less in the case of a large telescope, as the absorption is then greater on account of the thicker object-glass. The advantage of the large telescope in the case under consideration is to be found in the fact that the spectrum appears broader (higher), a condition which is more favorable to the recognition of details. In all cases, also, where a cylindrical lens must be used with small instruments, in order to obtain the breadth of spectrum necessary to make the lines visible, the large telescope is the more advantageous with respect to brightness, although not to the same extent as in the case of the stars, where the brightness of the image for different instruments is nearly proportional to the square of the aperture. The only advantage of the large telescope with respect to brightness seems to be that larger spectroscopes can be attached to it, and (similar construction of the apparatus being assumed) the slit opened more widely, without changing the purity of the spectrum as compared with the smaller instrument. This advantage is again partly annulled by the fact that the rays suffer a considerable loss by absorption in their passage through the greater thickness of glass, the amount of which can be numerically stated only for a particular instrument and known varieties of glass. Finally, the larger image in the focal plane of a large instrument makes possible the detailed investigation of the spectra of different parts of the planet's surface; but in the above are probably included all the advantages for the investigation of planetary spectra which are afforded by a telescope of the largest dimensions as compared with one of medium size.

It is true that in recent times the photographic plate has been made sensitive to all parts of the visual spectrum; the sensitiveness is, however, by no means uniform, and at present, therefore, not much is to be expected from the application of photography in the way of securing a permanent impression of the less refrangible parts of the spectrum. It is precisely in these parts, however, that the characteristic absorption bands of the planetary spectra lie. There can be no doubt that when photographic processes have been perfected in this direction, it

will become possible to determine the positions of the characteristic absorption bands in the spectra of the planets more accurately than by the direct observations which have alone been available hitherto. However, the accuracy which has already been reached would allow some conclusion to be drawn respecting the origin of the absorption bands (in particular those of Uranus) if we could only succeed in producing a similar absorption spectrum experimentally. Although no absorption bands are to be expected in the more refrangible parts of planetary spectra, the confirmation of this supposition by photographs of the spectrum is not without interest. The same photographs have a still higher significance in the case of the spectrum of Uranus, inasmuch as they disprove in the most emphatic manner the bold assumption which was advanced some years ago by Lockyer — that the spectrum of Uranus is to be regarded not as an absorption, but as an emission spectrum.

I have lately caused photographs of planetary spectra to be taken at the Potsdam Observatory, and the present paper is principally devoted to a discussion of the results. Mr. Huggins, to whom we are indebted for the first photographs of planetary spectra, has also kindly placed at my disposal the whole of the valuable material which he has collected, and with regard to which he has hitherto published only some very general statements.[1] I have accurately investigated all of Mr. Huggins' spectrograms, and give the results of the investigation after those obtained at Potsdam. Finally, I have collected the few known observations of planetary spectra which have been made since 1874, in order to give a complete supplement to my work on planetary spectra mentioned in the introduction.

Data respecting the construction of the two spectrographs, with which most of the Potsdam photographs of planetary spectra were made, are to be found in my papers on the new star in Auriga[2] and the spectrum of β Lyræ.[3] These two instruments have been used in

[1] *Phil. Trans.*, 1880, Part II, p. 687. *Proc. Roy. Soc.*, **46**, 231.

[2] *Abhandlungen der K. Pr. Akad. der Wissensch.*, 1893, S. 8.

[3] *Sitzungsberichte der K. Pr. Akad. der Wissensch.*, 1894, VI, S. 115.

connection with the thirteen-inch refractor; the improved spectrometer has been so used since 1893. Photographs of the spectrum of Venus, the brightest of all the planets, were already at hand. They were taken with the spectrograph of very high dispersion which I used in connection with the eleven-inch refractor of the Observatory for investigating the motions of stars in the line of sight. The apparatus is completely described in the memoir devoted to the results of this investigation, published by the Observatory.[1] A quite similar instrument, with only a single prism, but considerably exceeding in dispersion the instruments first mentioned, was sometimes used in connection with the eleven-inch refractor for obtaining photographs of the spectra of Mars and Jupiter.

Most of the photographs in the year 1892 were taken by Mr. Frost, those of a later date by Mr. Wilsing. For the measurements, which were all made by myself, a microscope was used which has already been described.[2] On some of the photographs, which were taken in the twilight, the sky spectrum is visible on each side of the spectrum of the planet, and these plates allow a direct comparison of the lines in the two spectra. On other plates the spectrum of some neighboring bright star was photographed on each side of that of the planet, and on these also a direct comparison was possible when the star belonged to the second spectral class. If the star was of the first class, at least the hydrogen lines could be identified, and they served as reference points for further measurements. Most of the plates, however, were made without comparison spectra, since the lines H and K and the group at G, which cannot easily be mistaken, served as reference points from which to determine by measurement the positions of other lines.

For determining the wave-length of a line, the distance of which from a known line is given in revolutions of the micrometer, I have used the customary and well-known method of drawing curves for each spectroscope from numerous measures

[1] Bd. VII, I Theil (Nr. 25), S. 7.

[2] *Publ. d. Astroph. Obs.*, Bd. VII, I Theil, S. 31.

of solar spectrograms and computing tables based on the curves.

A description of the apparatus with which Huggins obtained his photographs of planetary spectra is to be found in his classical memoir "On the Photographic Spectra of Stars."[1]

The length of the spectra is considerably less than that of the spectra obtained with the Potsdam photographic refractor. The following comparison will give an idea of the relative dispersion of the different spectrographs:

Linear Extent of the Spectrum from F *to the mean of* H *and* K.

Spectrograph I,	69^{mm}	In connection with the 11-inch refractor.
" II,	16	
" III,	7.0	In connection with the 13-inch refractor.
" IV,	8.6	
" of Huggins	5.3	

Spectrograph III was put together in a provisory manner, and in the spring of 1893 was taken apart again. Its prism was then used with Spectrograph IV. The collimator and camera objectives, both of which are achromatized for the chemically active rays, have a somewhat greater focal length than those of Spectrograph III.

In order to obtain wave-lengths from the measures of the Huggins photographs, I constructed a curve as before, based on the measurement of a number of plates on which the lines of the air spectrum are very strongly impressed.

MERCURY.

Three photographs of the spectrum of Mercury were obtained on March 30, 1892. On one of the plates the spectrum is surrounded by that of the bright sky, which is of such strength as to allow a very reliable comparison with the spectrum of the planet. The latter extends from λ 487 $\mu\mu$ to λ 380 $\mu\mu$, and the comparison showed a complete agreement of the spectra. Twenty-eight lines could be identified. On the second and third plates the daylight spectrum is not perceptible, and on account of the low

[1] *Phil. Trans.*, Part II, 1880.

altitude of the planet, the spectrum, in which some fifteen lines can be recognized, extends toward the violet only as far as K. A good plate was also obtained on April 4, 1892. Sixteen planetary lines can be identified with lines in the accompanying sky spectrum.

VENUS.

On each of the dates December 7 and December 29, 1888, and January 2, 1889, one photograph was obtained with Spectrograph I, while three plates were exposed on February 10, 1889. The length of exposure varied from 15^m to 20^m. All the photographs are good. I have measured portions of the best one, that of February 10, and have identified the lines with the lines of Rowland's atlas. A part of the results of the measurements, testifying to the great abundance of lines on the plate, is given below. The investigation of the whole spectrum, which required the work of several days, showed that over 500 lines in the spectrum of Venus between λ 460 $\mu\mu$ and λ 406 $\mu\mu$ are identical with lines of the solar spectrum, and that with respect to intensity also the agreement of the two spectra is perfect.

λ			λ		
4198.5	Strong	To some extent blended together, but still distinctly seen as separate lines	4217.6	Two delicate lines, blending together	
4198.8	Weak				
4199.2	Fairly strong line		4218.8	Diffuse line	
4200.2	Delicate line		4219.5	Line	
4201.0	Broad line		4220.5	Line	
4202.2	Very strong		4222.4	Strong	
4204.1	Line (preceding is a line at the limit of visibility)		4223.5	Perhaps double	
			4224.6	Somewhat wide	
4205.3	Band		4225.0	Fine line	
4206.9	Line		4225.8	Broad	
4207.3	Weak line		4227.0	Very broad and very strong	Double
4209.0	Weak line		4227.5	Strong line	
4210.5	Line		4230.0	Very strong	
4211.1	Fine line		4231.2	Very weak	
4212.0	Delicate lines		4233.2	Three or four lines, the strongest toward the red	
4212.8					
4213.8	Broad line				
4215.7	Strong line		4235.5	Weak	
4216.1	Line		4236.0	Very strong	

λ	
4237.2 4238.2 4239.0 4240.0	Very strong equal lines
4241.0	Broad; somewhat diffuse
4242.7 4243.5	Broad
4245.5	Very strong line
4246.2	Weak
4247.0 4247.5	Lines
4248.7	Weak band
4249.8	Very fine
4250.2	Strong line
4251.0	Strong line
4253.0	Delicate line
4254.3	Strong line
4255.5	Broad band; weak
4259.0	Broad band; weak
4260.4	Broad strong line
4261.8	Broad band; weak
4315.2	Strong
4317.0	Very weak
4318.9	Distinct
4321.0	Broad
4322.0	Very weak
4323.5	Band; perhaps lines
4325.2	Strong
4326.0	Very strong
4327.1	Broad; weak
4331.0	Broad; weak
4331.9	Fine line
4337.1	Very strong (Partially blended)
4337.6 4338.0	Fine lines (Partially blended)
4339.8	Broad; very strong
4340.7	$H\gamma$, broad and strong
4343.5	Broad; weak
4344.5	Broad; weak

λ	
4346.8	Doubtful
4348.1	Distinct
4349.1	Perhaps a line
4351.2	Well visible
4352.0	Strong line
4353.0	Very strong line
4355.2	Broad; weak
4358.8	Broad line
4359.9	Very strong line
4363.3 4364.3	Weak band
4366.5	Broad and diffuse
4367.8	Strong line
4370.0	Strong line
4371.2	Strong line
4373.0	Weak
4374.5 4376.1	Band; not distinctly resolvable into lines.
4377.5 4379.2 4381.0	Partially blended weak lines; perhaps still another line in the group
4383.6	Very strong broad line
4385.1	Broad; somewhat weaker than the preceding
4387.0 4391.0 4394.1	Line, Line (Group of lines; not resolvable)
4395.2	Very strong line
4400.0 4400.5 4401.5	Line, Line, Strong line (Partially blended)
4403.5	Weak line
4405.0	Very strong line
4407.0 4407.9 4408.5	Lines, not certainly resolved
4412.1	Fine line
4415.0	Very strong line

The spectrum of Venus has also been repeatedly photographed with the spectrographs having less dispersion. An

exposure of three-quarters of a minute was sufficient to give a spectrum which extended far into the ultra-violet.

A photograph taken by Mr. Huggins in 1879 shows the spectrum of Venus together with that of the bright background of the sky. More than eighty lines can be distinguished in both spectra, and not the slightest anomaly can be found in the spectrum of the planet. The photographic spectrum extends from λ 480 $\mu\mu$ to λ 320 $\mu\mu$. The last portion, above λ 328 $\mu\mu$ in the spectrum of the planet, and above λ 334 $\mu\mu$ in that of the sky, is very weak.

MARS.

Three photographs of the spectrum of Mars were taken on July 27 and 29, 1892, with Spectrograph II. With 10^m exposure (the first photograph of July 27) the spectrum is somewhat weak, although many lines can be seen in it. The best of the three photographs is the second one of July 27 (30^m exposure); it shows many very sharp lines. Between F and K, seventy-five lines could be identified with lines in the solar spectrum, and *no* deviation from the solar spectrum *of any kind* could be detected in this region. In order that a judgment may be formed as to the quality of the results furnished by the apparatus, I will give here the results of my investigation of a small part of the spectrum:

λ		λ		
4199.0	Broad and strong line	4260.5	Broad line	
4202.0	Strong line	4265.0	Weak band	
4204.0	Line	4272.0	Broad line	
4206.0	Line	4274.5	Broad line	
4210.5	Line	4280.5	Broad line	
4216.0	Strong line	4287.0	Broad line	
4219.5	Weak line	4290.0	Broad line	
4222.3	Weak line	4294.2	Line	
4227.0	Very strong line	4300.0	Broad strong line	
4233.5	Line	4302.5	Line	System of lines
4236.0	Strong line	4306.0	Line	
4238.0	Broad diffuse band	4308.0	Strong line	
4245.0	Broad band; diffuse toward the violet	4313.0	System of lines	
4250.0		4315.0	Line	
4255.5	Broad line	4326.	Band	

λ		λ	
4341.0	Line, diffuse toward the violet	4370.0	Broad, weak
4344.4	Line	4376.0	Broad band
4352.2	Strong line	4384.0	Very strong line
4360.0	Line		

Three excellent photographs were also obtained by Mr. Wilsing on November 1, 1894, with Spectrograph IV. On the first plate, which received 90 seconds exposure, the spectrum extends from F to a little above H; fifty lines can be recognized. On the second plate, which was exposed 3^m, there are forty-five lines, and on the third plate, which was exposed 5^m and shows the greatest amount of detail, seventy Fraunhofer lines can be recognized. The spectrum can be followed as far as $\lambda 373\,\mu\mu$ although it becomes very weak at $\lambda 383.6\,\mu\mu$.

Mr. Huggins informs me that he obtained several photographs of the spectrum in November 1894, which extend far beyond the violet, and which also show no departure whatever from the solar spectrum. No photographs had been made by him before this time.

As a supplement to the statements in my memoir respecting the observations of the visual spectrum made by Huggins in 1867, I have to add that Huggins has withdrawn the opinion which he expressed on the ground of his early observations; namely, that the predominant red color of Mars is due to groups of lines in the blue and violet.[1] The photographs also completely remove the doubts which remained after the observations of Huggins as to whether the lines which he perceived in the more refrangible part of the spectrum were special lines characteristic of the atmosphere of Mars, or merely the Fraunhofer lines, and their decision is in favor of the latter alternative.

Mr. Maunder, in 1877, also made observations of the visible part of the spectrum of Mars, chiefly for the purpose of discovering any possible traces of the absorptive effect of its atmosphere, and also with a view to detecting any differences in the spectrum of different parts of the surface.[2] The spectrum of Mars was

[1] *M. N.* **27**, 178.
[2] *M. N.* **38**, 34.

therefore compared with that of the Moon, at times when both bodies were at the same height above the horizon. The position of Mars when the observations were made was, however, unfavorable. The altitude was only from 24° to 26°, and it was a difficult matter to discriminate between the absorption lines produced by our own atmosphere and the lines of similar origin in the spectrum of Mars itself. Nevertheless, it appeared from the observations that some of these lines were broader and stronger in the spectrum of Mars than in that of the Moon.

A further result was that slight local differences in the spectrum of the surface were perceived, appearing as differences of relative intensity in entire regions of the spectrum.

My early observations, to which I will here refer briefly, agreed with the observations of Huggins in showing that Mars has an atmosphere of similar constitution to our own, the existence of which is revealed by certain groups of lines in the vicinity of the D and C lines, and by the telluric groups α and δ. Huggins was able to observe the planet when it was in a very favorable position, but the case was quite the reverse in my own observations, for Mars rose little more than 20° above the horizon, and at this altitude the absorption lines of our atmosphere are quite noticeable. It was only by most carefully taking account of this circumstance, and by making special observations of the Moon and fixed stars for purposes of comparison, that I could be certain that the delicate telluric groups of lines were strengthened in the spectrum of Mars.

In 1894 Mr. Campbell observed the spectrum of Mars under very favorable atmospheric conditions and when the planet was at a great altitude. As he was unable to detect any difference between the spectra of Mars and the Moon, when both of these heavenly bodies were at the same height, he concluded that the existence of an atmosphere on Mars cannot be demonstrated by means of the spectroscope.[3] The investigations of this zealous observer, carried out with the powerful instrumental appliances of the Lick Observatory, certainly require consideration, although

[3] *Pub. A. S. P.* **6**, 228, 1894. *A. and A.* **13**, 752.

in my opinion they are only entitled to equal footing with the earlier observations which have been cited; for, as I have already shown, the advantage of a great telescope in this particular case is not so considerable that the observations with smaller instruments need be entirely set aside.

Incited by this investigation of Campbell's, I repeated my observations during the opposition of Mars last year, but on account of unfavorable weather I was unfortunately only once able to observe the absorption lines in question. The observations were made on November 15, 1894, with Spectrograph IV (which can also be used for direct visual observations), attached to the thirteen-inch photographic refractor. As this telescope has a ratio of aperture to focal length of 1:10, it is considerably more efficient with respect to brightness than the Lick telescope. The atmospheric conditions were unusually favorable. The height of the planet was 43°, that of the Moon 25°. The following observations were made:

Group δ very distinct in the spectrum of Mars, weak in the lunar spectrum.

" a conspicuous in the spectrum of Mars, difficult to see in the lunar spectrum.

" λ 5945 } very distinct in the spectrum of Mars, equally well
" λ 5920 } visible in the lunar spectrum.

With low dispersion a narrow bright interval or band, somewhat more refrangible than D, is seen in the spectrum of our atmosphere, producing almost the effect of a bright line, although it is caused by a vacant space among the fine absorption lines which occur in the vicinity of the D lines. This bright band was easily seen in the spectrum of Mars, but was scarcely visible in the spectrum of the Moon. Hence I can only regard this observation as a confirmation of my earlier results. On December 12, 1894, when the atmospheric conditions were again excellent, the observations were repeated, with the same instrument, by Messrs. Scheiner and Wilsing, who were likewise convinced that the telluric lines appeared with greater distinctness in the spectrum of Mars than in that of the somewhat lower Moon.

Mr. Campbell's paper bears evidence of the circumspection with which his observations were made. He justly emphasizes the importance of making the breadth of the lunar spectrum the same as that of the planet. I may remark here, by the way, that I also took all conceivable precautions in my earlier observations; I not only made the lunar spectrum, and the spectra of such stars of the first class as I wished to observe for telluric lines, equal to the spectrum of the planet in breadth, but I made the lunar spectrum as nearly as possible equal to the spectrum of the planet in brightness. In only one point I do not agree with Mr. Campbell; namely, in his statement that the investigations of Thollon form a contribution to our knowledge of the spectrum of the Earth's atmosphere which is of special importance in this particular case. Twenty years ago the absorption lines of our atmosphere were already very accurately known; they were at any rate quite sufficiently well determined for the case under consideration, where it is a matter of less importance to resolve the diffuse bands into lines and to recognize the individual faint groups, than to draw conclusions from the general impression which is produced by all the absorption bands. Now I believe that in the endeavor to go too far into details, Mr. Campbell has always employed too high a dispersion in his investigation, thereby missing a detail of another kind which is of special importance in deciding the question whether there is a difference between the spectra of Mars and the Moon. Mr. Campbell also attaches especial weight to the observation that the absorption lines are not more conspicuous at the limb of the planet than they are at the center of the disk. I also have at no time succeeded in certainly detecting an increase in the intensity of these lines; but this circumstance is, in my opinion, very naturally explained, for the increase toward the limb would be a very gradual one, and finally a marked increase of intensity is to be expected only at the extreme limb of the planet, in such a narrow strip of the spectrum that fine details would no longer be recognizable.

I have received from Mr. Huggins the following information

with respect to the observations on the absorption lines of Mars, made by himself and Mrs. Huggins in 1894. On November 8, 10 and 15, the spectrum of Mars was compared with that of the Moon by both Mr. and Mrs. Huggins, and on December 15, 18 and 20 the spectrum of Mars was observed when the planet was nearly on the meridian. In the comparisons with the lunar spectrum care was taken to observe the two spectra, which differ so greatly in breadth and intensity, under as nearly as possible equal conditions.

On the three days of observation above mentioned the intensity of the atmospheric bands near D, which were the principal objects of attention, varied considerably in the lunar spectrum; still both observers independently and always accordantly estimated that the groups of lines on which the comparisons were chiefly based — a narrow band at λ 593 $\mu\mu$ and a broader one at λ 592 $\mu\mu$ — were always stronger in the spectrum of Mars. In like manner the broad atmospheric group which contains the D lines (λ 5887 to λ 5903), was repeatedly seen more distinctly in the spectrum of Mars, although the Moon was then at a low altitude.

The observers desire to withhold their decision for the present as to whether there are absorption bands in the spectrum of Mars which do not correspond with those of our own atmosphere; but they do feel justified in saying now that they have but little doubt of the existence of an absorption band, which lies a little on the more refrangible side of D, extending from λ 586 $\mu\mu$ to λ 584 $\mu\mu$, and which has not yet been recognized as a telluric group. The lines which are found in this region in the solar spectrum have probably made the decision somewhat difficult, but they could hardly cause a serious mistake. The visibility of this band is subject to changes, which, in the opinion of the observers, may depend upon the condition of the atmosphere of the planet.

I believe that it will be necessary to wait for still further observations, perhaps also those made from another point of view, before the question can be definitely settled. At the same time,

I must not allow the fact to pass unmentioned, that the existence of an atmosphere around Mars is distinctly indicated in the photometric observations of Müller.[1] This is in contradiction to the earlier view, based on a few observations by Zöllner, that the atmosphere of Mars must be extremely tenuous, since Mars, considered with reference to its phases, behaves like our own Moon. Müller's observations show that in its photometric behavior Mars is intermediate between Mercury and the Moon on one side and Jupiter and Venus on the other, and that with respect to density its atmosphere is more nearly comparable with that of the Earth. We should therefore hardly expect that no evidence whatever of the existence of a gaseous envelope would be revealed by the spectroscope.

(Concluded in the next number.)

[1] *Publ. d. Astroph. Obs.*, Bd. IX, p. 330.

SOLAR OBSERVATIONS MADE AT THE ROYAL OBSERVATORY OF THE ROMAN COLLEGE IN 1894.

By P. TACCHINI.

I HAVE the honor to send you a *résumé* of the solar observations made at the Royal Observatory of the Roman College, during the year 1894. The following are the results obtained for the spots and faculæ:

1894	Number of days of Observation	Relative Frequency		Relative Area		Number of Spot Groups per day
		of Spots	of days without Spots	of Spots	of Faculæ	
January	19	24.37	0	106.1	74.2	7.3
February	20	19.33	0	136.3	65.8	6.3
March	20	17.51	0	48.1	57.5	4.8
April	20	22.20	0	114.8	63.5	5.6
May	21	32.29	0	114.6	80.0	6.1
June	28	30.93	0	138.2	86.1	7.1
July	31	28.58	0	125.6	63.9	7.1
August	31	24.39	0	93.6	121.5	5.7
September	27	25.74	0	35.9	108.5	6.4
October	20	21.55	0	95.3	69.3	4.5
November	25	17.12	0	39.7	82.8	4.6
December	21	18.86	0	61.9	82.2	4.5

The spots are therefore decreasing as compared with preceding series. An examination of the records for 1891, 1892, 1893 and 1894 shows that from September, 1891, to the end of 1894 the Sun has never been free from spots; but the period of great area and frequency includes the year 1892, and continues until July, 1894, with the *maximum* about the middle of 1893. Even in this last series of observations we have noted the almost complete absence of extraordinary phenomena in the spot regions, as regards both quiescent and eruptive prominences; the spots have almost invariably been seen at the Sun's limb in a state of calm.

The results for the prominences are as follows:

1894	Prominences			
	Number of days of Observation	Mean Number	Mean Height	Mean Extent
January	14	6.00	37″.1	1°.6
February	18	7.17	37 .4	2 .6
March	18	8.11	37 .5	2 .2
April	18	5.00	38 .5	2 .3
May	17	5.94	35 .7	1 .7
June	26	6.38	32 .5	1 .7
July	31	4.71	36 .8	1 .8
August	30	5.20	36 .3	1 .8
September	19	5.53	38 .5	2 .2
October	16	4.56	32 .0	1 .8
November	22	4.64	38 .8	1 .7
December	17	3.41	35 .3	1 .8

There has thus been a progressive diminution in the phenomena of the prominences. While in the case of the spots characteristic secondary maxima occur in the series, the prominences have almost invariably indicated a state of relative calm, and true metallic eruptions have been lacking. A single large prominence was observed on December 24 by my assistant, Dr. Palazzo, in the southern hemisphere at latitude 29°.5, on the east limb, which at $11^h\ 26^m$ was 212″ high, and at $11^h\ 51^m$ had attained an elevation of 290″. Later the prominence commenced to diminish in height, and simultaneously moved toward the south. It seems probable that this was a prominence floating in the solar atmosphere, and that it did not take its rise at the point on the limb indicated by the first observations.[1]

The rather marked variations in the phenomena of spots do not agree with the relatively small variations of the prominences. As auroras have been few and faint, I find further confirmation for my belief that terrestrial auroras are more closely related to the phenomena of the chromosphere than to those of spots. This does not affect the general accordance that has been found to exist between solar and terrestrial phenomena.

ROME, January 10, 1895.

[1] [See in this connection Mr. Fényi's paper, p. 212.—Ed.]

ON A VERY LARGE SOLAR PROTUBERANCE OBSERVED DECEMBER 24, 1894.

By J. FÉNYI.

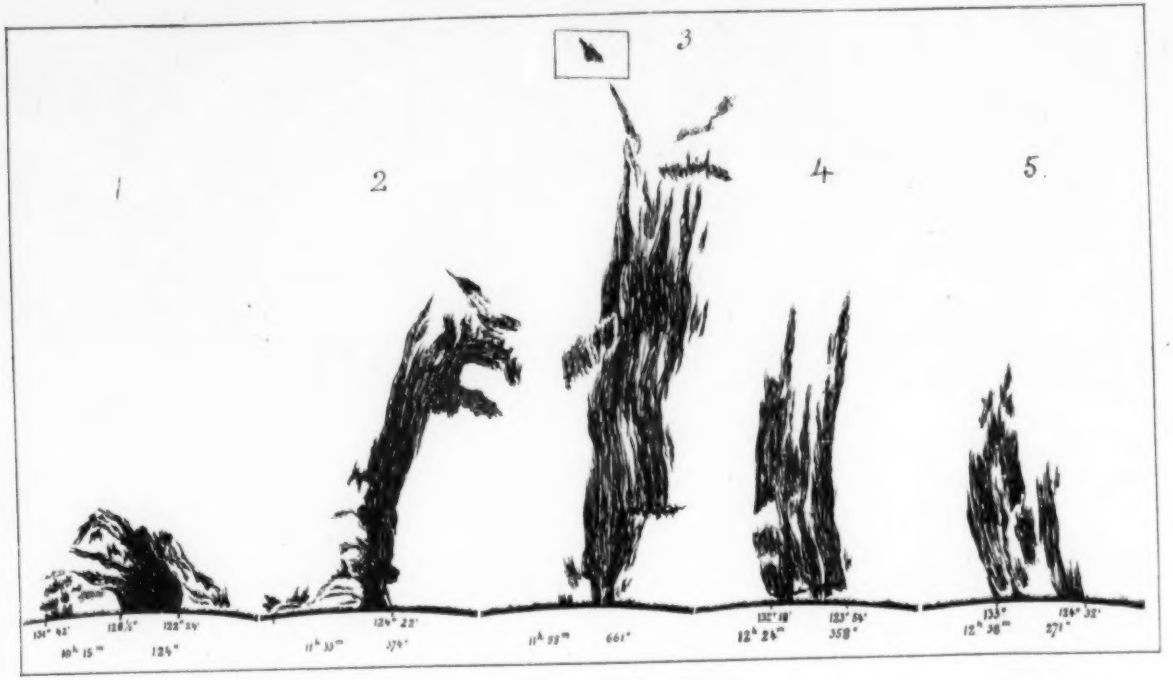
On the 24th of December of the year just past, one of those remarkable phenomena of the solar atmosphere was again observed at Kalocsa, which, on account of their rapid development and enormous dimensions, stand apart from others of their kind. Since the observation of a similar outburst on September 20, 1892,[1] there has been no other comparable with this one. The largest protuberance which I observed in the past year reached a height of only 261″.

On December 24, at $9^h\ 15^m$ Greenwich mean time, I found a very bright, but otherwise not remarkable protuberance, 124″ high, over the part of the Sun's western limb between —26° and —36° heliographic latitude. After completing the circuit of the entire limb, I turned to this protuberance again, and found it, at $10^h\ 15^m$, 216″ high, and evidently in a condition of rapid development. I now began to observe it regularly, confining myself, however, to a determination of its rapidly increasing height by successive passages across the slit, and continued until $12^h\ 9^m$, when it was far on the way toward dissolution. Twenty-six transits were observed, and these, with a few very hasty sketches, completely occupied my time during the whole appearance of the phenomenon.

The times marked by an interrogation are uncertain to the extent that the minutes were incorrectly noted. The figures thus marked in the table are given on the assumption that an error of 5^m was made in reading the clock. They have not been used in computing the height and the velocity of ascent. Of the accompanying sketches (Plate X) Fig. 1 only is a faithful representation of the form of the prominence; it was leisurely made during the ordinary observations. Fig. 2 was also carefully

[1] *Astronomy and Astro-Physics*, **13**, 122.

PLATE X



SOLAR PROTUBERANCE OBSERVED BY J. FÉNYI AT THE HAYNALD OBSERVATORY
DECEMBER 24, 1894

Greenwich Mean Time	Observed Height	Velocity in Kilometers	Remarks
$9^h\ 15^m\ 0^s$	124″		Height measured with the filar micrometer. (Fig. 1.)
10 17 59	212	+16	Height determined from time of passage across slit.
18 29	208		
18 59	220		
19 30	225		
20 1	211		
20 33	217		
			Sketch (Fig. 2) made in this interval.
10 33 45	374	+131	
34 31	388	+222	
35 20	405	+254	
36 9	417	+176	
37 3	434	+231	
41 33	519	+194	Velocity determined from the mean of the two transits.
42 45	512		Very bright up to a height of 310″.
48?	545		
49 23	568	+ 85	Very faint above 413″.
52? 4	626	+278	Very bright up to 338″; faint cloud some distance above.
55 21	661	+128	Very bright up to 444″; continuous mass up to 512″; detached portion floating above. (Fig. 3.)
11 6 31	402		
9 57	446		Upper part very faint.
11 20	464		Upper part very faint.
12 44	397		Bright up to 297″. (Fig. 4.)
24 51	358		
?	312		Bright up to 209″. (Fig. 5.)
38 4	271		Bright up to 271″.
38 57	272		Nothing seen above this height.
39 24	151		
12 9			Only a small elevation visible.

Though the times of the observations are given here in seconds, tenths of a second were used in calculating the heights.

made, but the form is naturally distorted, as the protuberance was ascending rapidly; during the 13^m required to complete the drawing the height increased $157''$. Figs. 3, 4 and 5, however, are prepared from very hasty sketches, and have no pretentions to fidelity, so far as details are concerned; they are reproduced here to show roughly the general outline and structure of the prominence, as well as the process of dissolution.

Certain peculiarities are revealed in the phenomenon now under consideration which are worthy of special remark. From $9^h\ 15^m$ to $10^h\ 17^m$ the protuberance was of a comparatively quiescent nature. It rose in this interval of $1^h\ 2^m$ with a mean velocity of only 16 kilometers per second. Indeed, in the first six transits hardly any ascending motion can be recognized, as may be seen in the above table. During the interval $10^h\ 20^m$ to $10^h\ 33^m$, when Fig. 2 was drawn, the protuberance suddenly began to rise; it rose $157''$ in the interval of 13^m, or with a mean velocity of 131^{km} per second. From thence it rose with still greater rapidity, until at $10^h\ 55^m\ 21^s$ it reached the enormous height of $11'\ 1''$ above the limb, or 0.676 of the Sun's radius. The dissolution which followed was as rapid as the development, but its progress was less uniform. At $11^h\ 39^m$ the height was only $157''$; at this point the observations were interrupted. At $12^h\ 9^m$ only a small elevation was found at the same place; the entire protuberance had dissolved. At 1^h there was also nothing more to be seen.

Now it is very remarkable that the prominence remained so long quiescent, and then ascended so suddenly and violently, although in the stage of dissolution it did not sink to approximately its former height, but disappeared down to the very level of the chromosphere. This singular behavior allows the conjecture that the forces which produced such an extraordinary ascent were of a peculiar kind; acting suddenly upon an already existing prominence, they caused a disruption in all directions, and brought the whole structure to a speedy end.

The structure of this prominence was quite the same as that of the two great prominences of the 19th and 20th of September,

1893, which were referred to above. It consisted merely of bright bands or strips, which, collected as it were in a bundle, lay approximately in the direction of the Sun's radius. The finer threads were here and there torn into small oblong fragments, very bright in the middle, with somewhat diffuse edges. This appearance was perhaps due to the rapid motion in the line of sight. I observed during the transits that the protuberance was considerably displaced from the image of the slit, sometimes toward the red and sometimes toward the blue. The amount of the displacement was measured once with the micrometer, the measurement agreeing with eye estimates in showing that the motion in the line of sight was approximately the same as that of ascent. The displaced image did not have the usual conical form, but was seen at times with the displaced edge of the slit quite sharply defined.

The breadth of the protuberance strikingly increased during the ascent; it was perhaps doubled. The dissolution proceeded from above downward, as may be clearly seen in sketches 3 to 5 and in the table. The uppermost parts betrayed the most rapid changes; they became paler and vanished. The greatest height measured was that of the cloud-like fragment which is shown in the upper part of Fig. 3, enclosed in a rectangular frame. It was easily seen during the transits, but when I made the drawing, working from below upward, it had already become invisible. It was therefore drawn only from memory, but probably had a shape and position somewhat like that shown.

The line $\lambda 6677$, which usually appears in such eruptions, was in this case invisible. There was also no luminous form on the Sun's disk which could be regarded as having any relation to the protuberance.

KALOCSA, Hungary.

ON THE DISTRIBUTION OF THE STARS AND THE DISTANCE OF THE MILKY WAY IN AQUILA AND CYGNUS.

By C. EASTON.[1]

IN comparing the results of his observations of the Milky Way with the *Durchmusterung* maps, the writer believes that he has found, in a number of places, remarkable analogies between the form of the Milky Way and the general distribution of the stars which Argelander has included in his great atlas. Luminous and obscure spots have frequently been observed in the Milky Way, at exactly the same places where condensations and vacant regions are found on the charts. The idea occurred to the writer to investigate these relations more thoroughly, together with the manner in which they could be made evident, and to publish such results as he should be able to obtain.

It is in the first place necessary, after having discussed the results obtained by different observers as to the naked eye aspect of the Milky Way, to determine, for certain places in the Milky Way, the details whose reality seems to be sufficiently well established. I have therefore divided the zones I wished to study into a certain number of parts, in such manner that a relative value of the intensity of the galactic light could be assigned to each. In this manner it is possible to put into a form suitable for numerical treatment the complex character of the luminous forms in the Milky Way; avoiding, at the same time, condensations and vacancies of an extremely local character, which would have a disturbing influence on the determination of the mean values. The number of stars for each half magnitude of brightness was then counted in the *Durchmusterung*, in trapeziums measuring 1° in declination and 4^m in right ascension. (The counts published by Seeliger, embracing 20^m in R. A., were hardly suitable for this study.) Star gauges have also been utilized as far as possible. Star photographs could also be used for this purpose,

[1] Dordrecht, Holland.

both for checking the drawings of the Milky Way compared with the star gauges, and for completing the results, in some measure, by the aid of counts made on the photographs themselves.

With the exception of the (unpublished) map of Julius Schmidt, which was inaccessible, the writer has been able to consult all the known drawings and descriptions of the Milky Way, namely: those of Heis, Trouvelot, Klein, Houzeau, Gould (for the zone in Aquila), Boeddicker, and Easton, and the unpublished drawings of Pannekock. The published series of star counts and gauges which were available were those of W. Herschel, those contained in Vol. II of the *Publications of the Washburn Observatory*, and those of Celoria,[1] while Dr. Th. Epstein, of Frankfort, has had the kindness to send me the results of his star gauges, unfortunately not yet published. I have moreover been able to consult the three photographs of regions in Cygnus, taken by Dr. Max Wolf with exposures of 3, 11, and 13 hours respectively, which were so well reproduced in *Knowledge* (October and December, 1891). The valued coöperation of Mr. Pannekock, of Leyden, has been of great service to me in the course of these researches.

These researches have led me, in the first place, to a zone contained between XVIII 20^m, XIX 40^m, $0°$ and $+6°$ (Aquila), and setting aside the gauges of Herschel and Epstein, which are not sufficiently numerous in that region, we arrive at the results summarized in the following table:

TABLE I.

	Division	Area in Sq. Degrees	No. of Stars 9.1–9.5 Argelander	No. of Stars 1–11(?) Celoria	Intensity of Galactic Light
A	XVIII 20, XIX 0 $0°, +6°$	60	955	2924	II
B	XIX 0, XIX 40 $0°, +6°$	60	1035	4476	III
A–B	.....	..	−80	−1552	−I
C	XVIII 20, XIX 0 $0°, +3°$	30	432	1189	I
D	XIX 0, XIX 40 $+3°, +6°$	30	566	2658	IV
C–D	.....	.....	−134	−1469	−III

[1] *Pubbl. Obs. di Brera*, XIII.

A zone situated in Cygnus between XX 20, XXI 40, +40° and +55°, was the object of analogous researches, after it had been divided into fourteen parts. In order to obtain more decided contrasts the strip contained between 47° and 48° was set aside; further, on account of the inequality of the areas of the divisions, the number of stars was replaced by the stellar density per square degree. The value attributed to the intensity of the galactic light in division A (Table II) is too small, on account of the influence of the adjoining great luminous spot $\eta-\gamma$ Cygni. The numbers for the other orders of brightness, inferior to the 9.0 magnitude, have also been inserted in the table.

TABLE II.

	Divisions	Stellar Density DM. per square degree							Intensity of Galactic Light
		1-6.5	6.6-7.0	7.1-7.5	7.6-8.0	8.1-8.5	8.6-9.0	9.1-9.5	
A	XX 20, XXI 0 +40°, +43°	0.49	0.71	1.03	0.85	2.72	5.89	20.49	II
B	XXI 0, XXI 40 +40°, +43°	0.36	0.18	0.40	1.11	2.19	5.40	22.90	IV
C	XX 20, XX 32 +43°, +47°	0.24	0.24	0.35	1.06	1.77	6.12	19.43	III
D	XX 32, XX 44 +43°, +47°	0.35	0.47	0.24	0.59	2.12	5.30	22.38	IV
E	XX 44, XX 56 +43°, +47°	0.82	0.82	0.94	0.94	2.47	5.54	22.26	V
F	XX 56, XXI 8 +43°, +47°	0.47	0.59	1.18	1.88	2.35	4.47	25.20	VI
G	XXI 8, XXI 20 +43°, +47°	0.35	0.24	0.71	1.06	2.12	7.07	22.14	V
H	XXI 20, XXI 32 +43°, +47°	0.71	0.71	0.47	1.30	2.59	6.00	25.79	VI
I	XX 28, XX 52 +48°, +50°	0.13	0.38	0.88	0.76	1.14	4.42	17.80	III
K	XX 52, XXI 16 +48°, +50°	0.63	0.38	0.25	1.52	2.15	6.31	13.64	II
L	XXI 16, XXI 40 +48°, +50°	0.51	0.63	0.13	0.88	2.78	6.94	19.82	IV
M	XX 20, XX 44 +50°, +55°	0.28	0.28	0.65	1.00	1.75	3.83	15.33	II
N	XX 44, XXI 8 +50°, +55°	0.42	0.37	0.60	0.65	1.06	2.72	10.67	I
O	XXI 8, XXI 32 +50°, +55°	0.32	0.32	0.78	1.06	1.71	3.23	14.68	II

For this zone, we have no systematic enumeration of stars down to a magnitude less than 9.5 Argelander, like that of Pro-

fessor Celoria. On the other hand, we have at our disposal eight gauges of Sir William Herschel and fourteen of Dr. Epstein. The latter cover an area of 1400 square minutes; the telescopic field of Herschel was 15′. It has been possible to complete the greater part of the gauges by the aid of counts of stars on photographs of the same regions, and by the stars in the *Durchmusterung* maps. Classifying the results of these gauges and counts under three heads, on the basis of galactic intensity, we obtain the following table:

TABLE III.

Intensity of Galactic Light	Area 1400 square minutes				Field 15′ in diameter Herschel
	Argelander 1–10?	Wolf, A. 1–11.3?	Epstein 1–12?	Wolf, B. 1–13.2?	
Feeble	9.	28.	65.5	165.	24.3
Mean	12.7	52.3	85.7	297.	202.
Strong	18.5	84.5	127.4	492.6	340.

It follows from the preceding table that the distribution of stars below the 10th and down to about the 15th magnitude agrees sensibly with that of the galactic light, and also with the distribution of Argelander's stars. Researches made specially for the purpose have, however, shown without doubt that, even for the zone in Aquila, the Argelander stars play no important part in determining the distribution of luminous forms in the Milky Way.

The general result of these investigations seems to be as follows:

1. In the zones which have been considered, the accumulation or sparse distribution of stars whose magnitude is even as high as 9.5 corresponds to the greater or less intensity of the galactic light.

In Table II there is only one exception to this correlation (D–E), and that anomaly is probably explained without difficulty by an erroneous evaluation of the mean intensity of the galactic light in that region. The fact should, however, not be lost sight of, that it is necessary to pay attention principally to

the analogy of the contrasts between the neighboring regions, in comparing the distribution of 9.5 magnitude stars and the intensity of the galactic light.

2. There is a real correspondence of the general outlines of the galactic forms with the distribution of stars of the 11th magnitude (Table I), and with the distribution of stars between the 10th and about the 15th magnitude (Table III).

3. Thus, in general, for the zones under consideration, *the faint stars which form the Milky Way are thickly or sparsely scattered in respectively the same regions as the stars in the last class of Argelander.*

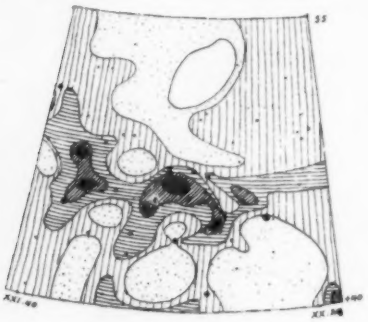


FIG. 1. Isophotic lines of galactic light in the zone α–π Cygni.

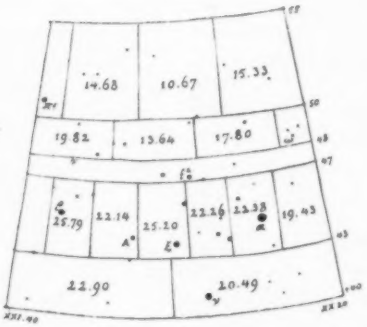


FIG. 2. Stellar density of 9.1–9.5 magnitude stars (Argelander).

4. It follows from the above, that, with a very great degree of probability, there is a real connection between the distribution of 9th and 10th magnitude stars and that of the very faint stars of the Milky Way; and that, consequently, the faint or very faint stars of the galactic zone are at a distance which does not greatly exceed that of 9th or 10th magnitude stars.

If the stars of, say, the 13th to 15th magnitude were really at the distances that would be indicated by the theory that their brightness is principally determined by their distance, there would be no reason why these stellar groups should have very nearly the same apparent distribution, in both galactic longitude and latitude, as the groups of 9th and 10th magnitude stars,

which would be separated from them by such enormous intervals.

It would therefore be necessary to admit that in all cases where these stellar condensations appear to have an appreciable galactic latitude, the *real* latitude of groups situated at such different distances along the line of sight is, for each of them, almost exactly proportional to these distances, — which appears to be absurd.

Although these researches include only a small part of the Milky Way, it should not be forgotten that the regions which are considered extend almost across its full width; that they are quite widely separated; and that the region in Cygnus, particularly, contains spots of great luminosity (like the spot α — A Cygni) bordering on spots which are very dark (the "coal sack" between f^2 Cygni and 6 Hev. Cephei). However, it is unnecessary to say that further researches on the aspect of the Milky Way to the naked eye are very desirable in order to extend the researches outlined above.[1]

[1] The writer will gladly take upon himself the task of centralizing observations which others might be inclined to send him, and of furnishing to observers, willing to coöperate with him in this way, any information or material (such as the galactic maps of Marth) that would be of service in such observations.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. III.

By HENRY A. ROWLAND.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4125.384		000	4130.804	Ba	2
4125.529		000	4130.847		000
4125.615		00	4131.013		0 N d?
4125.776	Fe	3	4131.151		000
4125.850		1	4131.271	Mn	1
4126.040	Fe	3	4131.419		000
4126.200	V	000	4131.507	Cr	0
4126.344	Fe	4	4131.606		000
4126.532		00	4131.748		0000
4126.673	Cr	2	4131.908		0
4126.798		00	4131.950		000
4127.007		1	4132.100	V	2
4127.070	Cr	00	4132.235	Fe	10
4127.225		00 N	4132.435		0 N
4127.426	Cr	0	4132.560	Ba?	0
4127.529	Ce	00	4132.690		3
4127.689	Ti	000	4132.863		1
4127.767	Fe	4	4133.062	Fe	4
4127.957	Fe	4	4133.284		000 N
4128.093		00	4133.441		000
4128.251	V-	6 d	4133.510		00
4128.461		00	4133.625		00
4128.543		00	4133.755	Fe	2
4128.658	Cr	000	4133.873		0000
4128.747		00	4133.965	Ce	0
4128.894		2	4134.010	Fe	3
4129.054		00 N	4134.159		0 N
4129.127		000 N	4134.345		0
4129.337	Ce-	3	4134.492	Fe ?	3
4129.476	Cr	00	4134.589	V-Fe?	3
4129.616		2	4134.675		1
4129.657		000	4134.840	Fe	5
4129.760		00	4135.050		00 N
4129.882		1	4135.191	Mn	0
4130.112		0	4135.325		0000
4130.196	Fe	2	4135.447		0 d?
4130.291		000	4135.610		0 N d?
4130.401		00	4135.838		00
4130.520		00	4135.915	Zr	0
4130.604		0	4136.090		00 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4136.245		0000	4143.200		00
4136.445		00	4143.316		000
4136.527		000	4143.430	Ti	000
4136.678	Fe	4	4143.572	Fe	4
4136.890		00 N d?	4143.664		2
4137.033		000	4143.782		0000
4137.156	Fe	6	4143.903		00 N
4137.272		0000	4144.038	Fe	15
4137.428	Ti, Mn	0 N d?	4144.130		00 N
4137.567		2	4144.238		1
4137.809	Fe, Ce	1	4144.353		00
4137.925		00	4144.402		00
4138.038		00	4144.538		00 N
4138.134		0	4144.674	Ce?	0 N d?
4138.288		00 N	4144.824		0000
4138.515		0 N	4144.923		00
4138.648		00	4145.018		00
4138.771		000	4145.152	Ce	0
4138.909		000	4145.242		0000
4139.008		0	4145.357		1
4139.140		00	4145.465		000
4139.244		0	4145.600		00
4139.378		00	4145.720		0 N
4139.524		00	4145.914		1 N
4139.611		000	4146.020		00
4139.764		00	4146.133		0
4139.885		00	4146.225	Fe	3
4140.089	Fe	6	4146.299		0
4140.216		0000	4146.544		00
4140.316		000	4146.655		00
4140.400	Fe?	0	4146.845		0 N
4140.558		3	4146.997		00
4140.611		00	4147.145		2
4140.910		0	4147.369		00
4140.985		00	4147.502		2
4141.096		000	4147.645	Mn	1
4141.208	Mn	0	4147.677		000
4141.465	Fe	000 N	4147.836	Fe	4
4141.690		0 N	4148.021		000
4141.809	La	0	4148.133		00 N
4142.025	Fe	4	4148.330		00
4142.180		00 N	4148.416		00
4142.330	Cr	2	4148.552		00
4142.465		2	4148.660		0
4142.562	Ce	00	4148.776		00
4142.629	Cr	2	4148.878		00
4142.744		2	4148.948	Mn	0
4142.923		0000	4149.077		00
4143.000		00	4149.285	C	0
4143.103		0	4149.360	Zr	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4149.533	Fe	4	4155.476		00
4149.657		0	4155.588		00
4149.700		00	4155.683		00
4149.857		000	4155.802		00
4149.923		2	4155.875		000
4150.056	Ce	00	4156.072		1
4150.139		00	4156.238	Nd	0
4150.258		00 N	4156.391	Zr	1
4150.411		4	4156.471		3
4150.535		00	4156.612		1
4150.608	Co	1	4156.764		00
4150.706		00	4156.831		1
4150.865		00 N	4156.970	Fe	3 d?
4150.964	Ce	00 N	4157.167	Mn	00 N
4151.129	Zr, Ti	1	4157.356	C?	0
4151.225		00	4157.398	C?	000
4151.360	C?	0000	4157.586		00 Nd?
4151.429	C?	000	4157.738		00
4151.569	C?	0000	4157.948 s	Fe	5
4151.638	C?	0000	4158.171	C	00
4151.726		00	4158.242	C	00
4151.826		00	4158.428	C	00
4151.925		0	4158.538	C?	0
4152.108	Fe, La	2	4158.586	C?	00
4152.242	Ce?	1	4158.700	Co	00
4152.343	Fe	3	4158.959	Fe	5
4152.474	C	00	4159.207		00
4152.547	C?	00	4159.353		5
4152.687	C?	00	4159.401		000
4152.759	Zr	00	4159.562		00
4152.927	Cr, La	0	4159.640		00
4153.071		00 N	4159.805	Ti	0
4153.222	Cr	00	4160.025		0 N d?
4153.283		000	4160.256		0
4153.404	C?	0000	4160.408		00
4153.542	Fe	1	4160.530		2
4153.652	C?	00	4160.722		0
4153.776	Co	0	4160.942		0
4153.971	Cr	1	4161.089		00 N
4154.071	Fe	4	4161.239		2
4154.265		2	4161.369	Zr-	2
4154.364		000	4161.471		000
4154.448		0	4161.571	Cr	00
4154.539		00	4161.682		4
4154.667	Fe	4	4161.834		0000
4154.824	C?	00	4161.961	Sr	1
4154.976	Fe	4	4162.110		000 N
4155.126		000	4162.281		00 N
4155.213		00	4162.454		00 N
4155.359		00	4162.623		1 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4162.825		1 N	4169.499		00
4163.068		00	4169.628		00
4163.144		000	4169.775		1 N d?
4163.281		000 N d?	4169.926		2
4163.449		00	4170.009	Cr	00
4163.516		000	4170.149		00
4163.642		0 d	4170.304		00
4163.818	Ti, Cr-	4	4170.372	Cr	00
4163.959		000	4170.506		00
4164.069		00	4170.646		00
4164.180		00	4170.797		00
4164.313		000	4170.900		000
4164.423		0	4171.068	Fe	4
4164.493		0	4171.213	Ti,-	4
4164.673		00	4171.433		000 N
4164.804		0	4171.597		00
4164.945		0	4171.720		00
4165.121		000	4171.854[1]	Cr,La,Mn,Ni,Fe	2
4165.277		0	4172.066	Ti, Fe	2
4165.328		00	4172.211	Al?	1
4165.550	Fe	3 d?	4172.296	Fe	2
4165.676	Cr	00	4172.447		000
4165.759	Ce,-	2	4172.509		00
4165.951		00	4172.641		0
4166.161	Ba	0	4172.748		00
4166.262		00	4172.803		2
4166.356		00	4172.923	Fe	4
4166.458		0	4173.045		000
4166.511		000	4173.136		1
4166.691		000	4173.309		00 Nd?
4166.823		00 N d?	4173.480	Fe	2
4167.013		00 N d?	4173.624		3
4167.126	Ce	0	4173.710		3
4167.197		000	4173.841		00
4167.332		000	4173.950		00
4167.438		8	4174.095	Fe	3
4167.560		00	4174.240		0
4167.737		1 N d?	4174.343		000
4167.884	C	1 N	4174.479		00
4168.025		2	4174.568		0
4168.133	Ni	2	4174.647		000
4168.279		0000	4174.807		00 N
4168.336		000	4174.973	Cr	0
4168.446		0000	4175.082	Fe	4
4168.634		00 N	4175.292		1 N
4168.784		2	4175.383		000
4168.957		00	4175.496	Cr	00
4169.110		2	4175.625		00
4169.253		00	4175.806	Fe	5
4169.411		00	4175.941		000

[1] Probably due to some common impurity of unknown origin. Is it Al? or Si? The Gallium line is also in this region, but I have no specimen of Gallium with which to determine its exact position. The Fe line is strong enough alone to account for it

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4176.074		1	4183.011		00
4176.222		000	4183.169		1
4176.427		00 N	4183.348		00
4176.569		00 N	4183.480	Zr	1 N
4176.739	Fe-Mn	5	4183.619		2 N
4177.034		0	4183.787		00 N
4177.153		00	4183.964		00 d?
4177.243		0	4184.158		4
4177.356		000	4184.472		2
4177.495	Nd	0	4184.641		0
4177.582		000	4184.794		000 N
4177.698	Fe	3	4185.058 s	Fe, Cr	4
4177.772		3	4185.155		000
4177.864		1	4185.310		00 N
4178.012		1 N	4185.523		00 N
4178.160		00	4185.705		00 N
4178.223		2	4185.807		00
4178.402		00 N	4185.939		0 N d?
4178.547		0	4186.130		00 N
4178.644		00	4186.280	Ti	1
4178.790		00	4186.496	Cr	0 N
4178.884		000	4186.622	C?	000
4179.025		3	4186.778	Ce-Zr	2 N
4179.106		0000	4186.955	C?	0000
4179.218		00	4187.204	Fe	6
4179.359		00	4187.409	La, C	00
4179.408	Cr, Co	0	4187.496	C	00
4179.542	V,-	3 d?	4187.615		000
4179.743		00	4187.747	Fe	2
4179.837		00	4187.878	Zr	0
4179.978	Zr	0	4187.943	Fe	5
4180.159		000	4188.019		3
4180.206	C?	00	4188.255	C	00 N
4180.314	C?	000	4188.479		00 Nd?
4180.405	C?	00	4188.608		000
4180.563		1	4188.741	C	0000
4180.732		00	4188.894		4
4180.839		000	4189.138	C,-	1
4180.970	C	2 N	4189.264		1
4181.065	Ti	000 N	4189.490		000 N
4181.243		00	4189.723	C,-	2
4181.353		0	4189.983	V	0 N d?
4181.515		00 N	4190.147	Mn	0 N
4181.708		1	4190.287	Cr	0 N
4181.919	Fe	5	4190.397	C	0
4182.136		2	4190.552		00
4182.376		00 d?	4190.687		00
4182.548	Fe	3	4190.874	C, Co	1 N d?
4182.755		00	4191.055		00 Nd?
4182.922		2	4191.240		00 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4191.321		000	4198.221	Fe	2
4191.433	C, Cr	0	4198.295		0
4191.595	Fe	6	4198.402		4
4191.843	Fe	3	4198.494	Fe	4
4192.017	C	00	4198.584		00
4192.171	Cr	0	4198.680		00
4192.258	La?	00	4198.800	Fe	3
4192.356	La?	00	4198.890		000
4192.557	C	00 N	4199.019	Cr	000 N
4192.728		2 N	4199.267 s	Zr-Fe	5
4192.910		00 N	4199.434		00
4193.072	C	00 N d?	4199.535		00
4193.274		00 N d?	4199.682		0000 N
4193.433		00	4199.831		00
4193.545	C	00	4199.901		000
4193.611	C	00	4200.045		1 N
4193.778		00	4200.148	Fe	2
4193.836	Cr	0	4200.261	Cr	00
4193.964	C	0	4200.451		000
4194.035	C	00	4200.611	Ni	1
4194.246		000 N d?	4200.761		1
4194.398	C	00	4200.858		0
4194.471	C	00	4200.946	Ti	1
4194.646		0	4201.089	Fe	3
4194.784	C	00	4201.227		00
4194.886	C,	1	4201.402		00
4195.006	Cr	1	4201.486		00
4195.155	C	0 d?	4201.585	Zr	0000
4195.318		000	4201.733		00
4195.492	Fe	5	4201.869	Fe, Ni-Mn	1
4195.572	C	00	4202.198 s	Fe	8
4195.684		1	4202.514		0 N d?
4195.785	Fe-C	2	4202.668		00
4195.987		00 N	4202.750		00
4196.108	C	0 N	4202.919		2
4196.372	Fe	4	4203.100		0 N
4196.516	C	00	4203.287		1 N
4196.576	C	00	4203.464		00 N
4196.699	La	2	4203.620	Ti	00 N
4196.837	Fe	1	4203.730	Cr	2
4196.929	C	00	4203.851		0000
4197.041	C	00	4203.935	Ti	00
4197.153	C	000	4204.101	Fe	3
4197.257 s	C	2	4204.163	La	4
4197.390	Cr	0	4204.359	Cr	0
4197.518		00	4204.499		00
4197.666		000	4204.622	Cr	0
4197.806		00	4204.761		00
4197.901		00	4204.884		1
4198.053		0000	4204.916		2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4205.054		000	4212.200		00 N
4205.186		1	4212.393	C	00 Nd?
4205.239		1	4212.564		00
4205.421		000	4212.801	Cr?	3 N
4205.545	Fe	1 N	4213.010	C	00
4205.702		2	4213.135		00 N
4205.894		000 N	4213.323	C, Cr	0 N
4206.059		00	4213.434	C?	000
4206.127		000	4213.579		00
4206.289		000 N	4213.679	C	000
4206.461		0	4213.812	Fe	3
4206.583		00	4213.991		0
4206.735		1	4214.070	Zr-C	0
4206.862	Fe	3	4214.198		00
4207.059	Cr	00	4214.295		000
4207.109		0000	4214.406	C	00
4207.291	Fe	3	4214.527		00
4207.410		000	4214.634		00
4207.566	Fe	1 N	4214.787	C	00
4207.788		00 N d?	4214.994		00
4207.982		0	4215.075	C	00
4208.110		0000	4215.221		0
4208.266		00	4215.337	C	00
4208.333		000	4215.459	C	00
4208.415		00	4215.581 s	Fe	2
4208.514	Cr	0	4215.703 s	Sr	5 d?
4208.609		00	4215.924		00
4208.766	Fe	3	4215.971		000
4208.941		00	4216.136 s	C	1
4209.015	C	00	4216.351	Fe	3 d?
4209.144	Zr	1	4216.516	Cr	0
4209.347		00 N d?	4216.760		1 N
4209.521	Cr	0	4216.966		000
4209.660	C	0	4217.061		000
4209.762		0	4217.220		00
4209.914	Cr	0	4217.365		1
4209.985	V	1	4217.420		1
4210.224	C	00 N d?	4217.720	La, Fe-Cr	5 d?
4210.494	Fe	4	4217.917		000
4210.561		3	4218.038		000
4210.662		0000	4218.214		00
4210.783	-C	00	4218.384		1
4210.860	C	000	4218.558	-Zr	1 N d
4211.127		3 N	4218.726		000
4211.350		00 N	4218.885		3 N
4211.512	C-Cr	0 N	4219.081		000 N
4211.675		00	4219.177		000 N
4211.795		000	4219.358		1
4211.899	Mn, C	0	4219.516	Fe	4
4212.048	Zr-	2	4219.580		3

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4219.756		000	4227.129		1 N d?
4219.895		00	4227.316		00 N
4220.064		00	4227.474		1 N
4220.212		1	4227.606	Fe	4
4220.330		00	4227.822	Ti	00
4220.509	Fe	3	4227.918	Zr	0
4220.643		0000	4228.103		1 N
4220.738	Mn	000	4228.265		000
4220.813		00	4228.475		00 N
4220.967		00	4228.716		000
4221.179		000	4228.879		1
4221.332		00	4229.032		000
4221.468		00	4229.206		00 N
4221.633		1 N	4229.419		000
4221.737	Cr	0	4229.566		0
4221.853		00	4229.677	Fe	2
4221.975		000	4229.926	Fe	3
4222.183		000	4230.075		1 N
4222.382 s	Fe	5	4230.267		00 N
4222.611		00 N d?	4230.413		00 Nd?
4222.768		0	4230.560	Cr	000
4222.890	Cr	0	4230.638		0
4223.061		00 N	4230.734		0
4223.256		1 N	4230.861		000
4223.396		0	4230.985		00
4223.509		00	4231.183	Ni	4 N
4223.643		1	4231.360		000 N
4223.738		1	4231.573		000Nd?
4223.891		0	4231.767	Zr	1
4224.060		00	4231.846		1
4224.138		000	4231.997		0000
4224.337	Fe	4	4232.111	Nb?	1
4224.463		0	4232.201		000 N
4224.619		0	4232.353		00 N
4224.673	Cr-Fe	3	4232.544		00
4224.792	Ti	00	4232.618		00
4225.020		2 N	4232.765	V	00
4225.206		000	4232.887	Fe	2
4225.378		0	4233.013		000
4225.490		000	4233.086	-V	1 N
4225.619	Fe	3	4233.328	Mn-Fe	4
4225.874		1	4233.404		00
4225.970		000	4233.564		000 N
4226.116	Fe	2	4233.772	Fe	6
4226.239		000	4234.171	Co, V	0 N
4226.381		000	4234.385		0 N
4226.510		0	4234.565		00
4226.584	Fe	2	4234.707	Zr	0 N
4226.724	Sr?	0	4234.895		000 N
4226.904 s g	Ca	20 d?	4235.054		000 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4235.155		0000	4242.167		000
4235.298	Mn	2	4242.322		0
4235.450	Mn	3	4242.443		0
4235.679		000	4242.535		2
4235.796		00	4242.615		2
4235.894		0	4242.766		2
4235.994		0	4242.897	Fe	2
4236.112	Fe	8	4243.060		0000 N
4236.279		1	4243.181		0000 N
4236.429	Ni	1	4243.364		1 d?
4236.540		00	4243.518		1
4236.714		00 N	4243.608	Fe	3
4236.801		00	4243.714		1
4236.966		1 d	4243.981		2
4237.119		0	4244.153		00
4237.240		1	4244.245		00
4237.339	Fe	3	4244.406		0
4237.412		1	4244.500		00
4237.655		000 N	4244.568		00
4237.836		0	4244.717		0000
4237.946		000	4244.888		00
4238.050		00	4244.971		00
4238.188	Fe	3	4245.104		0000
4238.398		00	4245.243		0 N
4238.555	La	1 N t?	4245.422	Fe	4
4238.778		00 N	4245.520		2
4238.918		0	4245.671		0000
4238.970	Fe	5	4245.772		0000 N
4239.107	Cr	00	4245.969		0000 N
4239.203		0000	4246.071		00
4239.304		000	4246.180		0
4239.525		2	4246.251	Fe	2
4239.642		00	4246.415		00 N
4239.759	Zr	00	4246.577		0 N
4239.890	Mn	3	4246.729		000
4240.014	Fe	3	4246.996	Y? Sc	5
4240.115		1	4247.279		00 N
4240.246		000	4247.464		1
4240.359	Zr	0 N	4247.591	Fe	4
4240.540	Fe	2	4247.726		0
4240.622		1	4247.886		0
4240.763		000	4248.057		000
4240.872	Cr	1	4248.215		0 N d?
4240.959		000	4248.384	Fe	2
4241.127		00 N d?	4248.485	Ti	00
4241.285	Fe-Zr	2	4248.575		1
4241.485		00 N	4248.696		0
4241.682		00 N	4248.882		2 N
4241.866		00 N	4249.102		2 N
4242.002		000	4249.272	Ti	00

Wave-length	Substance	Intensity and Character
4249.416		000
4249.507		00
4249.648		1 N
4249.797		2 N
4249.959		000 N
4250.205		000
4250.287 s	Fe	8
4250.629		00
4250.863		0
4250.945 } s	Fe	8
4251.071 }		1
4251.491		0 d?
4251.662		000
4251.783	Ti	00
4251.905	Ti	00
4252.043		000
4252.218		00 N d?
4252.388		00
4252.468	Co	0
4252.618		00 N
4252.785		0 N
4252.917		1 N
4253.157		1
4253.363		1
4253.522		00
4253.696		00
4253.888		0
4254.063		1
4254.236		000
4254.505 s	Cr	8
4254.821		000 N
4255.002		00
4255.134	Fe	2 d?
4255.406		1
4255.659	Fe, Cr	1
4255.791		1 N
4255.993	Fe	2 N
4256.177		00
4256.287	Ti	0
4256.366		1
4256.469		00
4256.575	Zr	00
4256.760		0
4256.966		0
4257.294		00 N
4257.517		00
4257.661		000
4257.815	Mn	2
4257.977		000
4258.079		0000
4258.201	Zr	0
4258.219		1 N
4258.477	Fe	2
4258.639		0 N
4258.774	Fe	2
4258.885		1 N
4259.113	Fe	2
4259.249		0
4259.305		0
4259.460		1 N d?
4259.664		000 N
4259.917		0 N
4260.151	Fe	2
4260.282	Fe	3 d?
4260.494 }		0 N
4260.640 } s	Fe	10
4260.768 }		0 N
4260.888		1
4260.991	Ti	0
4261.162		000 N
4261.376		2
4261.496	Cr, Mn	0
4261.679	Cr	2
4261.748	Ti	00
4261.891		2
4262.086		1
4262.142		1
4262.287	Cr	00
4262.498	Cr	0
4262.733		00
4262.864		0
4263.126		000
4263.290	Ti, Cr	2
4263.419		0
4263.581		00 N
4263.760	La	0 d?
4263.996		000 N
4264.128		1
4264.370	Fe	3
4264.431		00
4264.615		1
4264.738		00
4264.895	Fe	2
4265.083		00
4265.238		000
4265.418	Fe	2
4265.584		00
4265.696		0
4265.832	Ti	0
4266.081	Mn	2

THE MODERN SPECTROSCOPE. XI.

SOME NEW DESIGNS OF COMBINED GRATING AND PRISMATIC SPECTROSCOPES OF THE FIXED-ARM TYPE, AND A NEW FORM OF OBJECTIVE PRISM.

By F. L. O. WADSWORTH.

In the construction of astronomical spectroscopes, especially those designed for photographic purposes, rigidity is the most important mechanical condition that has to be fulfilled. The degree to which this may be satisfied in an instrument attached to a given telescope will in general depend on two things: (1) the size of the spectroscope in comparison with the telescope to which it is attached; (2) the design of the instrument, both as regards the optical and the mechanical features of construction, the latter being dependent upon and conditioned by the former.

As regards the first condition of rigidity, I have already shown that for a resolving power not exceeding 20,000 units, a spectroscope of not more than one-half inch aperture will, if properly designed, be equal in optical performance to one of four or five or even ten times that aperture, and will, of course, be much less expensive and bulky, and much more rigid than a larger instrument. For each resolving power there is a minimum efficient aperture, determined in the case of the grating by the possible fineness of ruling, and in the case of the prism-train by the number of prisms which may be conveniently mounted and adjusted. Practically this limit, in the case of the grating, is one inch to every 40,000 units of resolving power (for the first order spectrum), and in the case of the prism-train, one inch to from 40,000 to 50,000 units (60,000 to 75,000, if the source is sufficiently bright). For instruments of less than one inch aperture the question of optical design as affecting rigidity does not need to be considered, for with any of the usual forms of spectroscope, a sufficient degree of stiffness may be obtained without unduly increasing the weight or bulk of the mounting. When, how-

ever, it becomes necessary to use resolving powers as high as 75,000 to 100,000, or, as is sometimes desirable, to obtain moderate resolving power with low dispersion (as in the case of some classes of bolometric work), or with a large field (as in spectroheliographic work), apertures of two, three and sometimes four inches must be used. In this case it is of the highest importance to choose that design which, while efficient optically, will permit of the most rigid mechanical construction with the least weight and bulk; particularly if the instrument is to be used in measurements of precision, or for prolonged photographic exposures.

Of the two general types of instrument, the grating and the prismatic, the first has heretofore offered the greater number of advantages as respects a rigid construction, for, with the usual form of prismatic spectroscope, it is necessary, in order to observe different parts of the spectral field under the condition of minimum deviation, to vary the angle between the axes of the observing and collimating telescopes by an amount equal to the change in the angle of deviation for the light of different wave-lengths; a change which, in the case of a prism-train of only three dense flint or compound prisms, may amount to 15° or 20°. The necessity for providing for this motion makes it impossible to obtain as great stiffness of parts as can be obtained with a grating spectroscope, in which any part of the spectrum may be brought into the field of the observing telescope by a rotation of the grating alone, and the two telescopes may therefore be immovably fixed at a small angle to one another, as in Hale's spectroheliograph. But, on the other hand, the prismatic form of instrument has, for reasons which have been pointed out,[1] two important advantages over the grating; (1) in the more perfect utilization of the light, and (2) in the more uniform distribution of actinic intensity throughout the spectrum; advantages which render its use almost imperative when the spectra of very faint sources are to be measured or photographed.

[1] "General Considerations Respecting the Design of Astronomical Spectroscopes." *Ap. J.* January, 1895, p. 70.

For this reason a prism-train is almost invariably used in star spectrum work, the very class of work in which, on account of the prolonged photographic exposures necessary, rigidity is especially desirable. The advantages of a design which has all the advantages of a grating instrument in this respect, while still allowing of a ready examination of all parts of the spectrum at minimum deviation, is therefore evident. In a recent paper, "Fixed-Arm Spectroscopes,"[1] I have shown how this object may be accomplished by the combination of a mirror and prism in such relation that the plane of the mirror and the plane bisecting the refracting angle of the prism intersect on the axis of rotation of the system.

The first application of this principle to an astronomical spectroscope was in the case of the great spectroscope or spectro-bolometer of the Smithsonian Astrophysical Observatory, which is perhaps the largest spectrometer in existence, the collimator having a focal length of nearly ten meters and the observing telescope a focal length of about four meters. The conditions of the work required in this case that the spectrum should be passed slowly and continuously through the field of view at minimum deviation, and this necessitated, of course, with the usual construction, a regular and continuous movement of the arm carrying the observing telescope. It was soon found, as might be expected, that no great accuracy of measurement could be attained with such an arrangement, as the slightest current of air or vibration would cause a movement of the end of the arm through several seconds of arc.[2] By the adoption of the fixed-arm principle, which has enabled all parts of the instrument, except the prism and its attached mirror, to be rigidly fixed in position, this difficulty has been completely overcome; while the ease and certainty of driving the spectrometer circle at a uniform rate has been greatly increased by the removal of the great weight of the observing telescope arm and its counterpoise. Incidentally also the more or less troublesome minimum

[1] *Phil. Mag.* October, 1894; see also *A. and A.* December, 1894.

[2] A movement of 5″ would correspond to a movement of only $0^{mm}.1$ at the end of an arm over 4^{m} in length.

PLATE XI

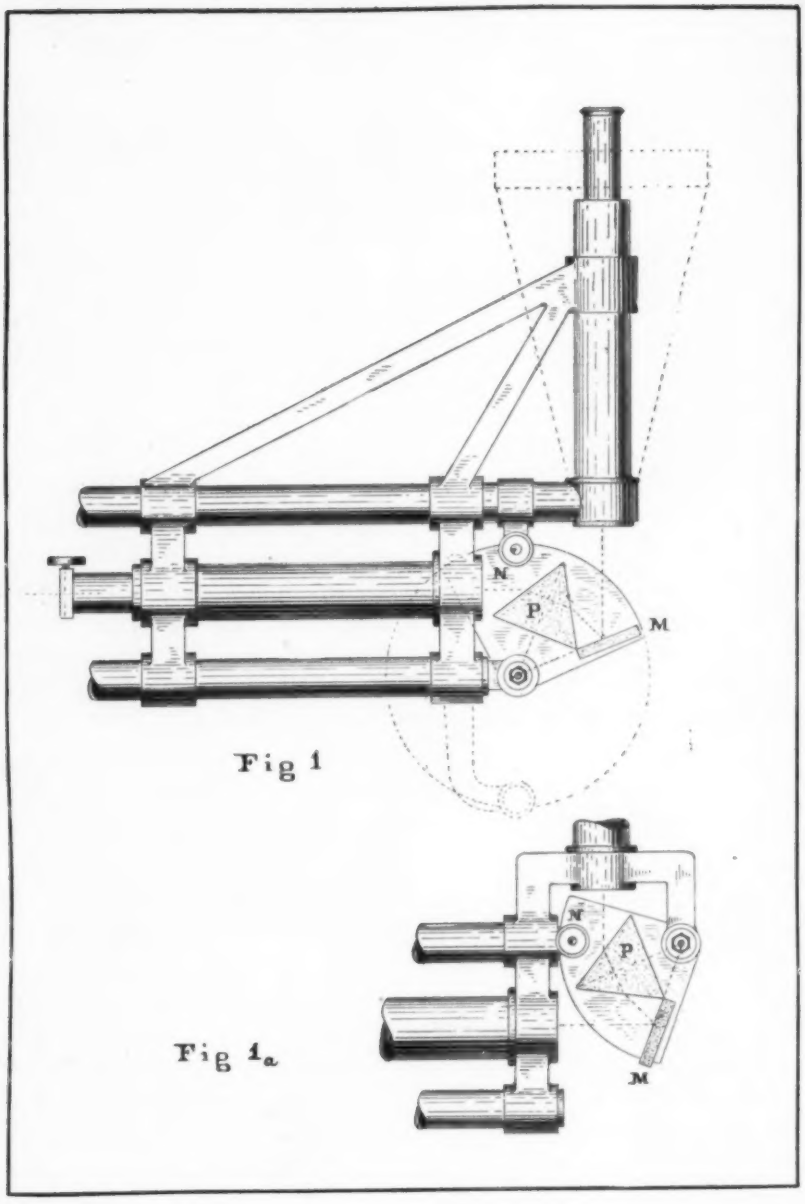


Fig 1

Fig 1a

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deviation attachment for the prism has been done away with. Successive settings on a particular line will now differ from one another by less than the limit of reading of the spectrometer circle, even when the traffic on the streets surrounding the Observatory is at its height.

The success which has attended the use of this type of instrument in the preceding case has led me recently to design several forms more particularly suited to smaller sizes of astronomical spectroscopes, and better adapted for use either as a prismatic or as a grating instrument without any change in the relative position of the two telescopes.

The first of these, which is designed for a single prism, either simple or compound, is shown in Plate XI. Here the general form adopted is that in which the angle between the two telescopes is 90°. The prism *P* and the mirror *M* are mounted together on a graduated table which may be segmental, or a complete circle as shown by the dotted lines, and the angular position read by means of a vernier or microscope *N*. The mirror may be placed between the prism and the observing telescope, or between the prism and the collimating telescope, as in Fig. 1a, the latter arrangement being in some respects preferable as giving greater freedom from diffused light in the field of the observing telescope. In the preceding design it is not possible to replace the prism-train with a grating.

In order to obtain a form in which this may be done without changing the relative positions of the two telescopes, as well as to obtain greater resolving power for a given aperture, it is desirable to use one of the double-prism arrangements shown in Plate XII, Figs. 2 and 3. In the first of these (Fig. 2) two similar prism-mirror systems are used, each mounted on its own segmental table, the axes of these tables being connected with each other and with the axis of a third graduated circle, N_r by means of gears, or better by steel cords (as in Fig. 2a), so that the two systems revolve in opposite directions with the same angular velocity as the graduated circle, which thus serves to measure the deflection of the ray which passes at minimum

deviation, and falls in the center of the field of the observing telescope. By means of the steel cord connections (properly designed to remain under a constant tension) equality of angular movement can be obtained to within a few seconds of arc, so that the multiplication of the number of centers of movement introduces no serious difficulty in this respect. At any rate, it would seem that as great accuracy could be attained in direct measurement as with a train of prisms provided with the usual form of automatic minimum deviation attachment, which involves a number of sliding joints and links; while the increased simplicity and rigidity of construction would make it considerably superior to the latter in measurement by means of comparison spectra. As will be seen from the figure, the axes of the two telescopes are in this case inclined to one another at a small angle (which may be made even less than shown, if desired, by altering the angle between the prisms and their attached mirrors), and intersect at the axis of rotation of the graduated circle. Therefore by removing the two prisms and placing a grating at the center of *N*, the instrument may be converted into a grating spectroscope without any change of any of the parts with respect to each other. The grating may of course be left permanently in position, as it does not in any way interfere with the use of the prisms. As in the former case compound prisms may be used instead of simple ones.

In Fig. 3 is shown a somewhat different form of fixed-arm double-prism spectroscope with but a single mirror and a single circle, which has already been briefly described in a previous paper.[1] In this case the mirror *M* is mounted on an arm which is connected permanently to the graduated circle of the spectrometer, and the two prisms (in this figure compound prisms are shown, but simple ones may equally well be used, as shown in the figure in the *Philosophical Magazine*)[2] are mounted together on a table, which is connected to the spectrometer table by an ordinary minimum deviation attachment (not shown in the

[1] "An Improved Form of Littrow Spectroscope." *Phil. Mag.* July, 1894.

[2] *Ibid.*, Fig. 4.

Fig 2a

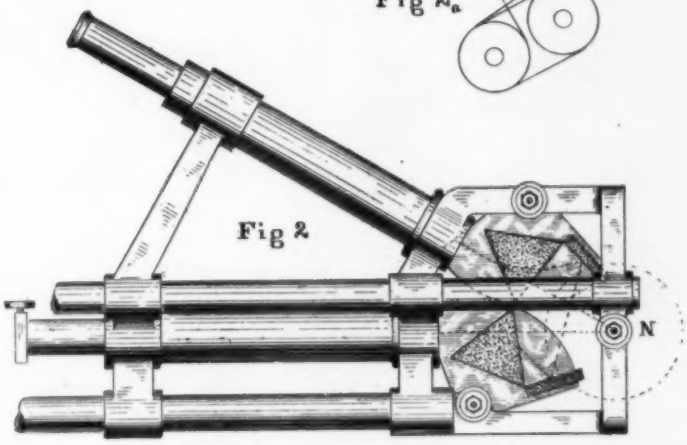


Fig 2

Fig 2b

Fig 3

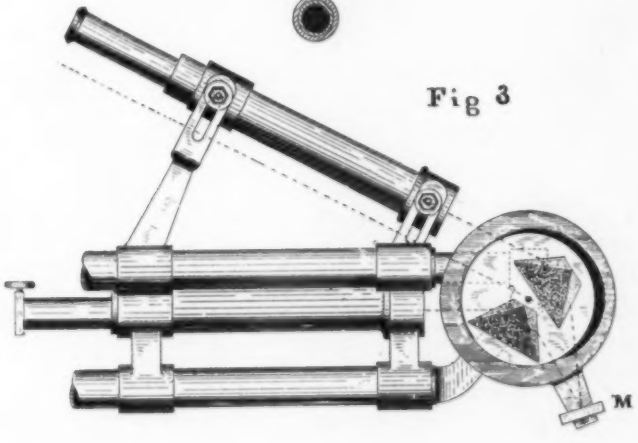


figure), so as to revolve at half the angular velocity of the latter. To use this instrument as a grating spectroscope, it is simply necessary to remove the two prisms and the minimum deviation attachment and place a grating on the same table, which is now clamped directly to the spectrometer circle. To more perfectly utilize the entire surface of the objectives of both collimating and observing telescopes, the axis of the latter should be displaced laterally until it intersects the axis of the former near the center of rotation (as shown by the dotted line, Fig. 3). This is easily accomplished, without sacrifice of rigidity, by slotting the braced support for the observing telescope, as indicated in Fig. 3.

In the preceding forms, the general object of the design has been to produce a fixed-arm spectroscope of as compact a form as possible, and one in which the general arrangement is such that either a grating or prism-train could be used without the necessity of changing the relative position of the different parts. For this reason the position of the mirror or mirrors with respect to the prisms has been so chosen that the axes of the observing and collimating telescopes make an angle, β, of nearly 180° with one another. But one great advantage of this general type of instrument is that by simply altering the mirror with respect to the prism, any value of β, from 0 to 360° may be obtained, with either one or two or more prisms, according to the conditions of use. In the spectro-bolometer of the Astrophysical Observatory, for example, it was found to be more convenient to use an angle $\beta=0$, or in other words, to adopt the direct-vision form of instrument[1] because of the arrangement of piers in the laboratory. Similarly in the case of compound spectroscopes, it might be more convenient in some cases to use instead of one of the forms shown, either the direct-vision form, or one in which the observing telescope was below, instead of above the collimator, and the angle β is therefore between 180° and 360°. The entire flexibility of this type of spectroscope in this respect is one of its important advantages.

[1] Case 4, Fig. 7, "Fixed-Arm Spectroscopes," p. 348.

It would not in general be advisable to use more than two prism-mirror combinations, both because of the increased loss of light by reflection, and the increased expense of the optical surfaces, and because of the increased difficulty of mounting and adjusting the systems with reference to each other. But we may obtain any number of transmissions through the prism-train, and therefore a resolving power equivalent to any number of prisms, by the use of double total reflection prisms, which are fixed at the end of the train, just as in Young's modification of the original Littrow form; except that in this case these reflection prisms are fixed and not movable with the train—a considerable advantage. The type of instrument is, however, adapted more particularly to spectroscopes where only a moderate resolving power is required, because the rigidity of the construction makes it possible to use almost any aperture that we please, and therefore allows the desired result to be attained by the use of one or not more than two prisms. Although, as I have previously shown, there is very little increased loss of light by reflection for any number of prisms above three, there is still a decided gain, amounting to nearly 40 per cent. of the total loss, in using only one instead of three; a gain which is well worth considering in the case of *very faint* star spectra, if it can be attained, as in this case, without any sacrifice of rigidity, even though the cost be very considerably increased. The only remaining difficulty in the use of a very large aperture is in obtaining a prism of sufficient homogeneity of material, but this difficulty may be overcome in a manner which will be discussed in the section devoted to the consideration of objective prisms.

When considerations of resolving power or dispersion demand the use of at least three prisms the use of the forms of the fixed-arm type so far described becomes impracticable (except, perhaps, in the case of the modified multiple transmission form already suggested) because of the multiplication of reflections. There is, however, another form which, although it has not so far been considered to any great degree in the design of astronomical spectroscopes, has decided advantages for the

purpose. This is the Littrow type of instrument which, as has been recently shown, is only one of the general class of fixed-arm spectroscopes, and may therefore be very properly considered in this connection. It has, of course, all the advantages of the class to which it belongs, as regards rigidity, and the further special advantage, which peculiarly adapts it to high resolving power — that of requiring (in its simple form) only two reflectors, one of them quite small, for any number of prisms.

Its principal disadvantage and the methods of overcoming it have already been discussed in the paper in the *Philosophical Magazine* already referred to. In addition to its getting rid of the general illumination of the field, the concave mirror form there described has two other features of construction which are specially advantageous for astronomical spectroscopes: (1) the concentration of nearly the whole weight of the instrument near the slit end, and (2) the position of the reflecting prism between the slit and the collimator instead of between the latter and the eyepiece. The first feature adds greatly to the rigidity of the instrument; the second makes the line of collimation at right angles to the axis of the telescope, and thus allows the main part of the spectroscope to be permanently attached to the latter without interfering in any way with its independent use.

In Plate XIII, Fig. 4, is shown an instrument designed on the above lines. In the figure *s* is the slit; *a*, the small total reflection prism which reflects the light from the slit to the collimating mirror *b*; *P*, a Littrow prism-train (which may be replaced by a grating if desired) of three or more prisms, simple or compound, with the usual automatic minimum deviation mounting; and *f* is the observing eyepiece, which may be replaced by a plate holder. It will be seen that the latter is so close to both the finder, *F*, and the small telescope, *t*, which serves to keep the image on the slit, that the observer may readily use either of these without moving from his position at the eyepiece of the spectroscope. Further, by simply removing the box which carries the slit tube and its adjustments together with the reflector, *a*, and eyepiece,

f, the telescope may be used for visual or micrometric observations without disturbing the main part of the spectroscope.

Fig. 5 shows a somewhat similar design of a Littrow grating or prismatic spectroscope which is still more compact and rigid. Here the light reflected from the slit by the first right-angled prism, *a*, falls upon a second, a_1, by which it is reflected along the side of the telescope tube to the collimator at *b*, from which it passes to the grating (or prism-train) at *G*, thence back again to *b* and finally to the observing eyepiece *f*. Instead of the concave mirror form we may use the modified Littrow form of Young and Lockyer, with separate collimating and observing telescopes *o*, *o'*, as indicated by the dotted lines.

This general form of construction will, it is observed, admit of the use of a collimator and observing telescope of any focal length we please (as great, in fact, as the focal length of the large telescope), without sacrifice of rigidity and without any objectionable increase in bulk. As in the preceding form, all parts of the spectroscope save the small portion which carries the slit tube may be left permanently in position without interfering in any way with the ordinary use of the telescope, an advantage of very considerable moment in the case of large instruments, on account of the saving of the time and trouble involved both in attaching and detaching the instrument itself and in the readjustment of the two sets of balance weights on the telescope tube. The only objection which can be raised against this or the preceding form is the use of the reflectors or total reflection prisms *a*, a_1, in the path of the rays from the slit to the collimator.

In general, three objections may be raised against the use of reflectors in a spectroscope train.

1. The increased loss of light due to the additional reflections and, in case reflecting prisms are used, the additional absorption of the latter.

2. The impairment of definition due to the increased number of optical surfaces and to the distortion of those surfaces due to changes of temperature, etc.

3. Changes in adjustment due to accidental disturbances of

Fig 5

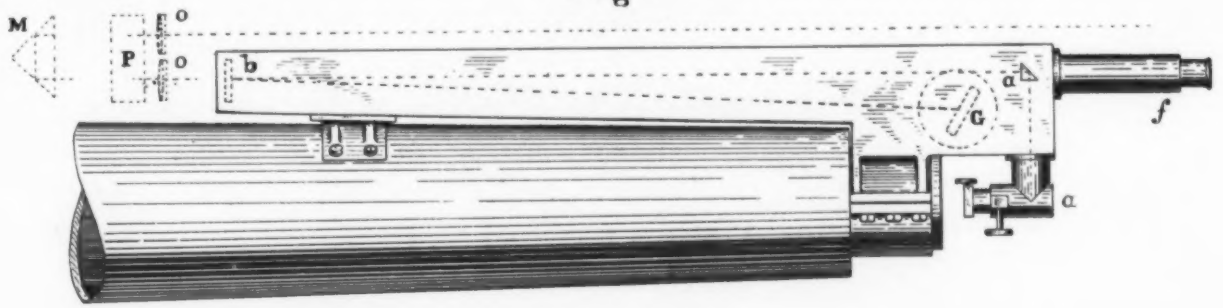


Fig 6

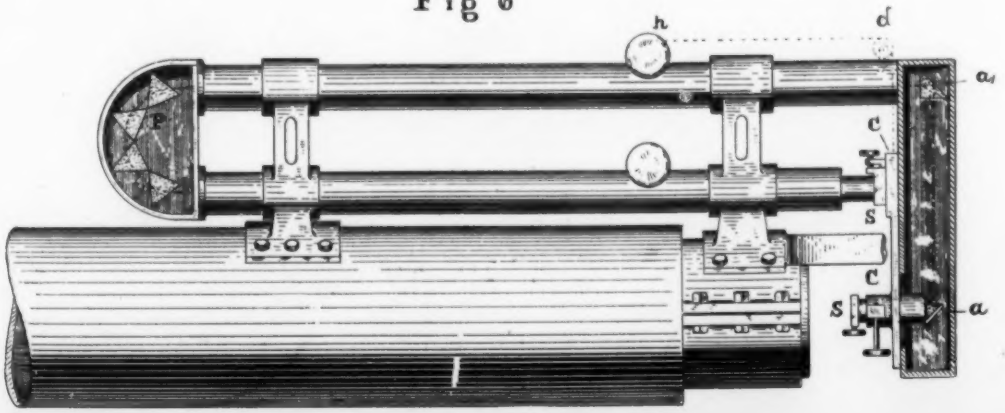
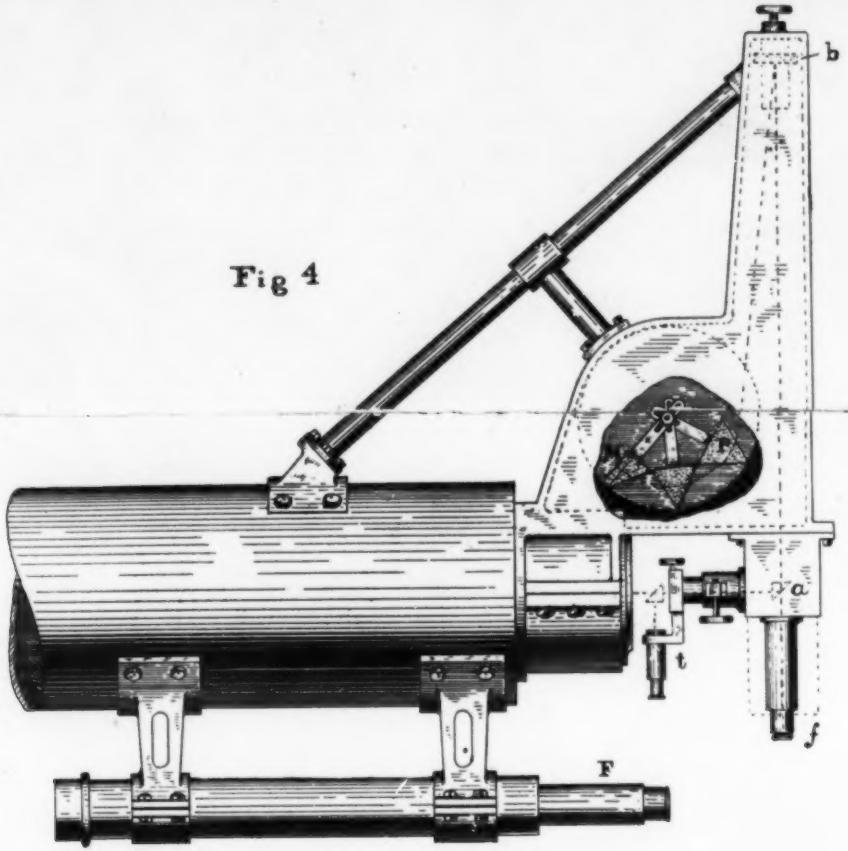


PLATE XIII

Fig 4



the position of the reflectors by reason of temperature changes in the mountings, vibration, etc.

As all of the forms so far described in this paper have involved the use of one or more reflecting surfaces, it is of importance to consider these objections somewhat in detail and to show that none of them affect to any sensible degree the efficiency of the spectroscope for either visual or photographic or bolographic purposes.

As regards the first, the effect of two reflections in diminishing the brightness of the spectral image is insignificant in comparison with the effect of the prism-train or grating. A well-silvered surface or a total reflection prism will reflect 97 to 98 per cent. of the incident light, and the loss due to the two reflections must therefore amount to only about 5 per cent. of the reflected beam, while the loss by reflection in a single prism amounts to about 18 per cent., or over three and a half times as much. The proportionate amount of light lost by diffusion and multiplication of spectra in the case of the grating is of course still greater. We may therefore employ at least two reflections for every prism in the spectroscope train without seriously diminishing the quantity of light transmitted. The loss by absorption, in case total reflection prisms are used, will be correspondingly small, because the prisms themselves are small in comparison with the prisms of the spectroscope train.

As regards the second objection, there is hardly need to consider it at all when such surfaces as Mr. Brashear, Mr. Clark or the Henry Bros. turn out are at our disposal. It is only necessary to refer to the magnificent definition of the Coudé Equatorials and to remember that the difficulties of making and supporting such large surfaces as are there used are many times greater than would ever be encountered in the instruments at present under discussion. It is to be noted, moreover, that all of the surfaces are behind the slit and receive only the radiations which pass through the latter, the energy in which is far too small to heat them appreciably, even in the case of solar work.

The third objection is of comparatively little importance in the case of visual observations, but of very great importance in the case of photographic or automatic bolographic observations, because in these we rely absolutely on the adjustment of the spectroscope remaining the same during the whole time of exposure, which in some cases may be several hours. The effect of any displacement of the different parts with respect to each other is greater in a spectroscope in which reflectors are used than in one in which no reflecting surfaces are involved, and under unusually severe conditions of use the former instruments would undoubtedly be less satisfactory than those of the usual form. But I think that the results which have been obtained by Young, Lockyer, Huggins, Kayser and Runge, Rubens and others with various forms of Littrow spectroscope in which from three to sometimes as high as ten or more reflecting surfaces were used, as well as my own experience with some of the forms which have just been described, quite justifies me in the statement that when these instruments are carefully designed and properly used no difficulty need be apprehended from a change of adjustment during the longest exposures. I have already spoken, in the earlier part of this article, of the admirable steadiness and constancy of adjustment of the large fixed-arm spectroscope of the Astrophysical Observatory at Washington; an instrument in which the two reflecting surfaces, *i. e.*, the prism-mirror and the concave reflector which serves as objective of the view telescope, are nearly four meters apart; and, as I have stated in a previous paper, I have taken solar spectrum photographs (in the red and infra-red region) of between one and two hours' exposure, with the form of instrument shown in Fig. 4, in which the lines were perfectly sharp and showed no tendency to the broadening which would have resulted from any change in adjustment during that time. It is true that this time is short as compared with the exposures sometimes given on star spectra, but it may be remembered on the other hand that the conditions of use were *unfavorable* to steadiness in both the above cases, particularly the latter, in which the frame of the instrument was made entirely of

wood. At night the conditions both as regards uniformity of temperature, and freedom from vibration and earth tremors, are very much better than during the day. I was, myself, formerly quite as skeptical as the majority of astronomers seem to be in regard to the use of reflecting surfaces in a spectroscope train, but, in view of the preceding experiences, I have not hesitated to employ them freely in my recent designs, whenever any decided advantages could be attained thereby.

I believe that the advantages of the use of concave mirrors in place of lenses especially have never been fully appreciated, or rather, perhaps, their disadvantages have been greatly overrated.

The form of spectroscope last described would seem to be particularly suitable for prominence spectroscopes and spectroheliographs, one form of which is shown in Fig. 6. In this the slit, *s*, and the first reflecting prism, *a*, which is placed just behind it, are mounted together on a carriage, *c*, which slides on ways parallel to the direction of the reflected ray $a\,a_1$. This makes it possible to examine any part of the Sun's surface or limb without moving either the solar image or the spectroscope. In order to automatically maintain the slit at the principal focus of the collimating lens, the latter may also be mounted on a sliding carriage, connected to the carriage *c* by means of a steel cord or suitable system of levers. For the dispersion system we may use either a train of fixed prisms adjusted once for all to bring the C or K line into the field of the observing telescope, as shown in the figure, or, better, a train of adjustable prisms with independently movable reflector, like that used by Professor Hale in his last form of spectroheliograph.[1] Or, since the second reflector a_1 is fixed in position and may be set so as to reflect the light from *a* in any direction, the axis of the collimating telescope may be placed at such an angle with that of the observing telescope that a grating or combined grating and prismatic train like that of Figs. 2, 2a, or 3 may be used. When used as a spectroheliograph the carriage, *c*, is also made to carry a photo-

[1] *A. and A.* October, 1894; see also *A. and A.* March, 1893.

graphic plate, which moves just behind the slit, *s*, of the image telescope. The slit and photographic plate are, therefore, fixed rigidly with respect to one another, and to make the exposure it is only necessary to move the carriage, *c c*, which carries both, across the solar image which is formed on the first slit plate, *s*, the image itself and all other parts of the spectroscope remaining fixed in position.

All lever systems and movable connections between the slit and photographic plate, or between the two slits, are thus entirely avoided, and as both slits are fixed in the axes of their respective telescopes there is no distortion of the photographic image

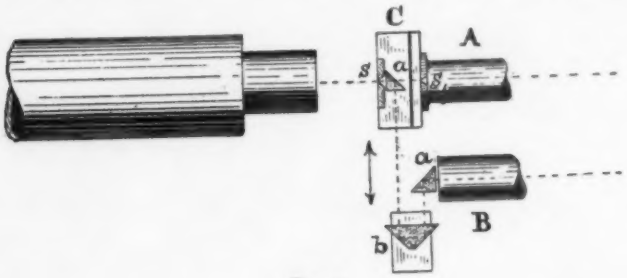


FIG. 7

(except that due to the curvature of the line on the second slit). In fact the result optically considered is the same as that produced in the most recent spectroheliographs of Hale and Deslandres, in which the entire spectroscope is moved bodily across the solar image, and it was the description of these instruments (*Astronomy and Astro-Physics*, November, 1894; *l'Astronomie*, June, 1894)[1] which suggested to me the preceding simple substitute.

To avoid the necessity for moving the collimating lens with the slit carriage (although there is not really any serious mechanical or optical objection to this), the modification shown in Fig. 7 may be adopted. The ray from the first (slit) reflector, *a*, is received by a second double total reflection prism, *b*, by which

[1] The priority of suggestion of this form of instrument belongs to Professor Hale, who described it in an exhaustive article on the general subject of the spectroheliograph published in *Astronomy and Astro-Physics* for March, 1893, over a year before M. Deslandres' instrument was constructed.

it is reversed in direction and returned to the second reflector, a', fixed in the axis of the collimating telescope, B, which may be parallel to the axis of the observing or image-forming telescope, A, or, as in the preceding cases, inclined to the latter at a small angle.

The axis of the observing telescope, A, may be immediately in line with the axis of the large telescope, and in this case the photographic plate is mounted immediately behind the slit and first reflector, making a very light and compact arrangement. The carriage, c, which carries the slit, first reflector and plate is connected to the plate on which b is mounted by a simple arrangement of levers or multiplying gears, so that the latter moves with it in the same direction but at one-half the speed. This motion of the second reflector serves only to keep the distance $s\ a\ b\ a'$ constant, and does not therefore need to be especially accurate either as to amount or parallelism, as any slight angular displacement of the double reflector, b, is without effect on the direction of the reflected ray $b\ a'$.

By removing the carriages c and b, moving out the slit s_1 until it occupies the position of s, and inserting an eyepiece at a' in place of the reflecting prism, the instrument is converted into an ordinary spectroscope. Conversely any spectroscope of the usual design may be simply and inexpensively converted into a spectroheliograph by the addition of the two carriages c and b and the system of reflectors a, b, a', or by the addition of c and the reflector a' alone, if the former be directly connected to the collimating lens as in the preceding arrangement (Fig. 6).

THE OBJECTIVE PRISM.

The many advantages which an objective prism possesses over any form of compound star spectroscope as respects simplicity and high resolving power with a maximum brightness of spectra, would make its use more general, were it not for the difficulty of obtaining and mounting the very large prisms necessary for a telescope of even moderate size.

The largest aperture which has been heretofore used with this

type of instrument is that of the photographic telescope of the Harvard Observatory, although an objective prism has now been completed for the new Bruce photographic telescope which is, I believe, of the same aperture as the telescope itself, *i. e.*, twenty-four inches.

Since the difficulty of obtaining homogeneous blocks of glass is very much less for thin than for thick plates, it would seem that in making a very large prism it might be advisable to build it up out of a number of comparatively thin prisms, as shown in Fig. 8, cemented together into one solid prism. Since there is no difficulty in obtaining thin plates as large as the disks which

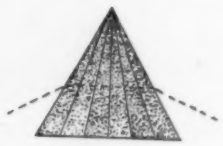


FIG. 8

have been cast for the largest telescopes, it would seem perfectly practicable by this method to make a prism of an equally large aperture and of any refracting angle, and consequently of any resolving power that is desired. Another advantage of this method of construction would be that the central prisms might be made of glass of a greater density than the lateral ones and the advantages of the compound prism, as regards greater resolving power and dispersion for a given volume of glass and a given loss of light, realized.

But in an objective prism we require usually only a moderate resolving power, the increase in aperture being advantageous simply on account of the larger quantity of light and greater brightness of the resulting spectra. Hence a better arrangement than the use of one very large prism would be the use of several smaller prisms of the required refracting angle (to produce the required linear dispersion at the focal plane of telescope) arranged "in parallel" so as to cover the whole surface of the objective, as shown in Fig. 9.

This enables us to utilize the entire aperture of even the

largest objective without an undue increase in the size and bulk of the prisms. In order that the optical performance of this system shall be perfect, it is necessary that the prisms shall be of the same material, that they shall have the same refracting angle, and that they shall each be set at approximately the same angle to the axis of the telescope. Of these conditions the first and third are easily satisfied, and the degree to which the second may be fulfilled depends only on the skill of the optician. Since the two faces of plane glasses or sextant mirrors may be made parallel to within less than a second of arc, it would seem easily possible to work the refracting angle

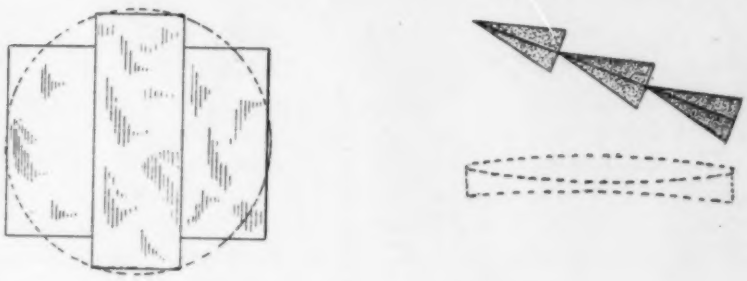


FIG. 9

of a prism to within this same limit of accuracy. This would mean that the angular deviation of the superposed spectra from the different prisms would differ from one another by less than half a second of arc, a quantity which is considerably less than the usual width of the image of the source as broadened by diffraction and aberration. No great degree of care need be exercised in setting the prisms at the same angle to the axis of the telescope, for a difference of 5′ from the position of minimum deviation in a white flint prism of 30° changes the angle of deviation of the refracted ray by only about 0.3″. For this same reason changes in the relative position of the prisms during use, due to changes of temperature or other causes, will have little or no effect on the purity of the resultant spectral image.

UNIVERSITY OF CHICAGO,
January, 1895.

Minor Contributions and Notes.

THE DESIGN OF ASTRONOMICAL SPECTROSCOPES.

In the first number of The Astrophysical Journal Professor Wadsworth, employing the methods of physical optics, and assuming constant resolving power as a basis of comparison, has discussed in a very complete manner the conditions on which the efficiency of spectroscopes for astronomical purposes depends. In 1891 I published in the *Sidereal Messenger* an elementary paper on the same subject, from a different standpoint, employing the methods of geometrical optics, and adopting constant dispersion as a basis of comparison. The purpose of the present note is to compare some of the conclusions which were reached in these two papers.

The condition of constant resolving power is much the more philosophical of the two bases of comparison, but it is obviously unsuitable for the purposes of an elementary discussion. The observer generally has to deal with a given dispersion, and constancy of resolving power involves the variation of other quantities which are more naturally regarded as constant. The approximate methods of geometrical optics are also better suited to such a discussion, and they are sufficiently accurate for all cases which occur in astronomical spectroscopy except the case of the Sun, and possibly that of the stars.[1] For a thorough discussion the resolving power is more suitable as a basis, and too much value cannot be attached to the exact methods of physical optics, as a means of indicating the limit to which our results tend under the best conditions of observation. Whichever method of treatment is adopted, the conclusions, except in certain special cases, should be the same, and in general the conclusions of Professor Wadsworth and myself either agree, or differ on some point of comparatively small importance. In one respect, however, they differ very widely, and that in a matter of such importance that its further discussion seems to be very desirable. Whereas I have advocated the use of a small number of large prisms with correspondingly large spectroscope aperture (the limiting size to

[1] In this case the width of the slit must be considerably greater than its theoretical value to obtain full illumination, doubtless on account of the motion of the image.

be determined by practical considerations of cost and weight), Professor Wadsworth concludes that a spectroscope of proper construction should have a small aperture and a large number of small prisms. He also concludes that correct lines have not been followed in the construction of existing telescopes, or rather that more efficient instruments could be built on different lines, provided the plan of construction should include the telescope itself.

As stellar spectroscopy is becoming a part of the regular work of a well-equipped observatory, it is a matter of importance to settle this question as to the lines which should be followed in the construction of instruments. Now I believe that the best spectroscopes of modern construction are more correctly designed than Professor Wadsworth seems to think, and that they could not advantageously be replaced by instruments of the construction which he recommends. It is of course true, as Professor Wadsworth says, that spectroscopes have always been made to fit previously existing telescopes, but I doubt whether a radical change in any part of the design would be advantageous.

My reasons for this opinion, which are all of a practical character, are given below; at first I will leave the case of a star out of consideration. Since the brightness of the spectrum *with constant resolution* is independent of the aperture of the spectroscope, it is evident that a given resolution can be obtained by employing either a small number of large prisms or a large number of small prisms. Which method should be employed becomes after all principally a question of opinion based on practical experience. The advantages of the latter method are, according to Professor Wadsworth, greater lightness, stability, and cheapness of construction, with some others of less importance. The greater lightness may be conceded, although a spectroscope of from 1 to 1½ inches aperture is by no means a heavy burden for a 12-inch equatorial, and it can be attached or removed without difficulty. Under the condition of similar form, the advantage with respect to rigidity might lie with the smaller instrument, but with a large number of small prisms, each of which would be subject to slight displacements during a long exposure (for prisms cannot be very tightly clamped) the small instrument would probably be less rigid than the large one; moreover, there is no difficulty in making a spectroscope of the size mentioned above so rigid that displacements due to flexure are of less importance than those due to changes of temperature under the ordinary circumstances of observation. The cost of construction can hardly be regarded

as following even roughly any particular law with respect to size, and the larger number of small pieces required in Professor Wadsworth's construction, with their accurate fitting, might easily raise the cost to that of the larger form.

With a large number of prisms, errors in the surfaces are not likely to be compensatory, as in ordinary optical work the tendency is invariably to make the surfaces convex.[1] In the present state of the optician's art, however, errors in the surfaces are less to be feared than irregularities of density in the glass. The effect of such irregularities would, perhaps, be less with the small prisms. Finally the loss of light by reflection would be somewhat less in the case of the large prisms.[2] So far, then, a departure from the usual construction of a spectroscope does not seem to be advisable.

But the most serious objection to the small aperture and high dispersion is, perhaps, the following: Since the linear extent of the spectrum cannot exceed a certain limit on account of the faintness of the light, it would be necessary to use a camera objective of very short focus. As compared with the other form of spectroscope having equal resolving power, the field would therefore be very small, and only a short range of spectrum could be sharply photographed on a single plate. Except for a very few special purposes this would be decidedly objectionable. I am at present engaged in some investigations in which the small field obtained even with a long focus camera is a serious inconvenience.

In the case of a star, which may now be considered, a telescope of the largest possible aperture is of course desirable. Professor Wadsworth advocates the use of a reflector, which unquestionably has some great advantages, the greatest of all being the absence of chromatic aberration. To this reflector he would give a very short focal length, principally in order to contract the linear dimensions of the diffraction pattern, and thus allow the use of a correspondingly narrow slit. But since the angular aperture of the collimator must be equal to that of the telescope, and it is impracticable to make a sufficiently good lens

[1] The limiting error of the surfaces of the prisms made by Brashear for the Allegheny spectroscope is only $\frac{1}{10}\lambda$, but errors amounting to several wave-lengths are frequently met with in ordinary prisms.

[2] About 25 per cent. less, according to Professor Wadsworth's tables, if we compare three prisms with six prisms of half their size. The advantage is less with a greater number of prisms.

of the large angular aperture required, the usual collimating lens must in that case be replaced by a parabolic mirror. This seems to me to be a highly objectionable arrangement, as according to all experience a mirror cannot be depended upon when stability is required; in fact, a reflector is as much out of place in a spectroscope designed for long exposures as it would be on a meridian circle. If, however, we abandon the use of the reflecting collimator, we must again fall back upon the usual construction, with an angular aperture of something like 1:15.

In making the above remarks I would not at all be understood as underestimating the valuable discussion of Professor Wadsworth, which contains many novel and interesting features; but I wish to point out that experience cautions us not to accept the conclusions too hastily, although they are founded on theoretical principles which are undoubtedly correct. Perhaps it would be advantageous to make a compromise between conflicting requirements by using a reflecting telescope of unusually large angular aperture, say 1:10 or 1:8, and a refracting collimator with triple objective. The three lenses would allow the focal length to be made short with sufficient exactness in the corrections, and the construction of the lens would be facilitated by the fact that the question of field does not have to be considered.

An interesting point raised in Professor Wadsworth's paper may appropriately receive notice here, although it is not immediately connected with the present subject. Professor Wadsworth deduces the width of the nebular lines from certain photographic observations of mine on the Orion nebula, although with due reservation as to the reliability of the data. The data are reliable in the sense that they represent correctly the observed facts, but the method of observation is altogether too rough to give results of value. Briefly reviewed, the entire method is as follows: The brightness of a spectral line increases up to a certain limit as the slit of a spectroscope is widened, and then remains constant. The limiting slit-width is, in the case of monochromatic light, $s_0 = \frac{\lambda}{\psi}$. If the light includes wave-lengths ranging through $\Delta\lambda$, Professor Wadsworth has shown that the limit is $s_0' = \frac{1}{\psi}(\lambda + \tau\Delta\lambda)$. Hence if the limiting slit-width can be determined experimentally the value $\Delta\lambda$ can be found. In photographing the spectrum of the Orion nebula with the Allegheny spectroscope, I found that the density of the lines on the negative fell off sensibly if the slit was made

narrower than .001 inch, when it was still three times the theoretical limiting width for full illumination by monochromatic light. From these and other data relating to the instrument, Professor Wadsworth obtained the value $\Delta\lambda = 2.6$ tenth-meters.

Now as a matter of fact the width of the nebular lines is much less than this. In my observations of nebulæ at the Lick Observatory the width of the lines as ordinarily observed was only 0.35 tenth-meter, and I have *seen* the lines when their width was much less than this, and probably not more than 0.1 tenth-meter. Probably they are as fine as the lines of hydrogen at the lowest possible pressure. The explanation of the discrepancy is, I think, that which I gave at the time; it depends upon a peculiarity of the photographic action which, as shown by other experiments, may produce very considerable effects. The structure of a photographic plate seems to be too coarse for such experiments as these, or at least for such applications. It is to be hoped that further observations on this interesting subject will be made with more suitable apparatus.

JAMES E. KEELER.

NOTES ON SILVERING SOLUTIONS AND SILVERING.[1]

Since the first introduction, a half century ago, of Liebig's method of silvering glass by deposition from the solution of a silver salt, a number of modifications of the process (consisting usually in some variation in the reducing agent employed to precipitate the silver) have been proposed, some designed to cheapen the cost of the method by securing a larger percentage of deposited silver, and others to render the deposited film harder and more enduring. Of this latter class that which was originated by Brashear is one of the most successful, as it gives a film so hard and adherent that it may be rubbed vigorously with the hand or with a pad of cotton, while it is still wet from the silvering bath, without injury. A description of the process was published some years ago by Mr. Brashear[2] and is now very generally used by professional makers both in the United States and in England, but it is not as generally well known among scientific men as its merits deserve. It was described to me about a year ago by Mr. Brashear himself, and since that time it has been used exclusively in silvering

[1] From the *Zeitschrift für Instrumentenkunde*, January, 1895.

[2] *English Mechanic*, 1883; also in a pamphlet, "Silvered Glass Reflecting Telescopes and Specula," by J. A. Brashear; Best & Co., Pittsburg, Pa.

the large mirrors (one of which is 36^{cm} in diameter) used on the siderostat and spectro-bolometer of the Smithsonian Astrophysical Observatory. It has given excellent results, and for the benefit of those who are unacquainted with it I will describe it briefly, giving the proportions both in grams and cubic centimeters and in the English units used by Mr. Brashear.

The composition of the reducing solution is as follows:

Loaf sugar or rock candy	-	90 gms	or 840 grains
Strong nitric acid (sp. gr. = 1.22)		4 cc	or 40 grains
Alcohol - - - - -		175 cc	or 3½ ounces
Distilled water - - -		1000 cc	or 25 ounces

This is made up by dissolving the sugar in the distilled water and then adding the alcohol and the nitric acid. It should be prepared at least a week before it is used and, unlike most solutions for this purpose, the longer it stands the better it gets. A quantity sufficient to last a year or more may therefore be made up at one time.

The silver solution is an ammoniacal solution of the oxide, precipitated as in the ordinary process from the nitrate, to which just before using is added a solution of caustic potash in the proportion of ½ gram of potash (KOH purified by alcohol) to 1 gram of the silver salt. If very much silvering is to be done, both the ammoniacal solution of silver and the caustic potash solution may be kept in stock and mixed as required, but better results will be obtained if this part of the silvering bath is made up as it is wanted.

The amount of silver nitrate, potash and ammonia, and the corresponding quantity of the reducing solution required for different sizes of mirrors will be about as follows:

For Mirrors	Area	Silver Nitrate (Ag_2NO_3)	Caustic Potash (KOH)	Ammonia[1] $NH_4OH + H_2O$	Reducing Solution
30 cm diam.	707 sq. cm	15 gms	7.5 gms.	12 cc	85 cc
25 " "	491	11	5.5	9	65
20 " "	314	7	3.5	6	40
15 " "	177	4	2.0	3	25
10 " "	78.5	1.8	0.9	1½	10
5 " "	19.6	0.5	0.25	½	3

In English units these quantities correspond to 120 grains of nitrate of silver and 60 grains of potash for a mirror 8½ inches in diameter.

[1] The amount of ammonia will of course vary with the strength of the solution. The quantity here indicated is for ammonia of sp. gr. about 0.88.

The bath is made up as follows: The silver nitrate and the potash are dissolved separately, each in about 100^{cc} of water per gram of salt. To the silver solution is added about one-half the ammonia, and the remainder is diluted with distilled water in the proportion of 1 to 5, and then added more slowly until the silver precipitate is barely redissolved. During the last part of the process the solution should be constantly agitated, and the vessel which holds it should be occasionally lifted or shaken so as to wash down the sides. (A Florence flask is much to be preferred to a beaker for this operation, because of the greater facility with which it may be handled.) The potash solution is now added and mixed thoroughly, and if a precipitate remains, dilute ammonia is added until it is not quite redissolved, using the same precautions as before. At the end the liquid should have a slight brownish color, indicating the presence of a little free silver oxide. It should be allowed to stand for a few minutes, and then if there are many floating particles it is filtered through coarse filter paper or cotton, after which it is ready for use.

A slightly different mode of procedure is recommended by Mr. Brashear. About $\frac{1}{10}$ of the original silver solution is reserved, and, after the balance has been treated as already described, the reserve silver is added slowly until another distinct precipitate is formed; then a little more ammonia until it is redissolved, then a few more drops of silver, and so on until all the reserve silver has been added; taking care to make the last addition silver solution and not ammonia.

If care is taken to use as dilute a solution of ammonia as recommended above, and to agitate the solution thoroughly during its addition, the first method will be found perfectly satisfactory. It is, however, well for beginners to adopt the latter plan until they learn to recognize from the appearance of the solution the presence of free silver oxide.

"*It is useless to attempt to silver without having a slight excess of silver in the solution.*"

The solution having been filtered as above described (if there are no floating particles, this filtering will be unnecessary) the required amount of reducing solution is added, the whole thoroughly mixed and poured into the dish in which the silvering is to be done, and the mirror, which has previously been cleaned (of which more hereafter), immediately immersed face up or down, as the operator prefers. I myself always prefer to silver face up, as the progress of the deposit

may then be watched, and arrested when it has proceeded far enough. When silvering face up, however, the solution must be kept in constant motion to prevent particles of precipitated silver from settling on the glass surface.

In a few minutes after mixing the bath turns a dark brown color, which, as the operator proceeds, gradually becomes lighter and lighter, until at length it is nearly clear again. At a temperature of 70° F., which is best for securing good results (if much lower than this the film will be too thin, and if much higher, too soft), the operation will be finished in from ten to fifteen minutes. The mirror is then lifted out, placed in an inclined position under a stream of clean water, and the whole surface rubbed vigorously with a pad of *clean* absorbent cotton

FIG. 1

until the white film on the surface of the silver is entirely removed, and the whole surface is bright and clear. The mirror is finally set on edge on a sheet of blotting paper in a warm dustless place and allowed to dry. If the operation has been successful, a bright hard surface will be obtained which will need no polishing, and will therefore be free from the minute scratches always produced by the polishing pad, no matter how carefully the latter may be prepared and kept. One essential condition to success is the use of *clean wash water*, not necessarily distilled water, but water which is at least free from free alkalies and acids, and from any suspended sediment.

The foregoing process is of especial value where non-diffusive coats of silver are desired, for example, on concave mirrors of that form of Littrow spectroscope recently described by the author.[1]

[1] "An Improved Form of Littrow Spectroscope," F. L. O. Wadsworth, *Phil. Mag.* July, 1894.

When half silvering, *i. e.*, when a very thin semi-transparent coat—such as is used on telescope objectives for solar observations, or on the "separating glass" of the "interferential refractometer"—is required, the old Rochelle salts process will give the most satisfactory results as regards uniformity, although the film is less enduring than that produced by the Brashear process. As the directions given in the books in regard to this process are generally meager and often misleading, the following notes on certain precautions necessary in order to insure success in this, the most difficult of all silvering operations, may be of service to those who have had but little experience in the art.

In the first place pure chemicals, while not absolutely essential, are yet of considerable advantage, and it is best to purchase them C. P. of some

FIG. 2

reliable dealer in chemical supplies. If the ordinary silver nitrate and Rochelle salts of commerce are used, recrystallization is desirable. In making up the silver nitrate solution great care should be taken to avoid an excess of ammonia, by leaving the solution decidedly brown before filtering. In making up the reducing (Rochelle salts) solution I first bring the distilled water to boiling, and then add first the silver and then the Rochelle salts, both of which have previously been dissolved in the smallest possible quantity of boiling water. The boiling is then continued from twenty minutes to half an hour, or until the gray precipitate has collected together in the form of a compact powder at the bottom of the flask, leaving the supernatent liquid nearly clear. It should then filter perfectly clear, and remain so after cooling. Much seems to depend on the length of time of this boiling; as regards the performance of the silvering bath, in general the longer the boiling the more rapidly will the deposit take place, and the more uniform it will be.

Cleaning the glass for silvering.—It may truly be said that no other one condition of success is one-half as important as a proper cleaning of the surface to be silvered. In four cases out of five a failure to secure good results is due to improper cleaning. The necessity for this

is especially apparent in half silvering, for the deposit must here be absolutely uniform from the very beginning of the operation. Merely bathing the surfaces with acid, potash, and alcohol in succession, as recommended in the books, is far from sufficient, unless the surface be unworked.[1] The best plan is to wash the surface thoroughly with a pad of absorbent cotton. Then rinse in clear water, and transfer to a dish filled with strong nitric acid. Again go over the whole surface thoroughly with a pad of cotton, held on the end of a bent glass rod of the form shown in Fig. 1. The surface must be rubbed hard, not merely lightly brushed over. If care is taken to flatten down and round over the end of the rod, as shown in the figure, and to pick out a piece of cotton free from any gritty particles, there will be no danger

FIG. 3

of injuring the surface. Then pour off the acid or transfer the glass to another dish filled with a strong potash solution, and repeat the rubbing. Finally rinse, and place in a dish of pure distilled water until ready for silvering.

The use of the alcohol as recommended by the books is not only unnecessary but, unless the glass be very thoroughly washed subsequently, is actually detrimental. If any considerable amount of organic matter is present, it should be removed *before* commencing the cleaning, either by washing with alcohol, or better by a bath of sulphuric acid to which some permanganate of potash has been added. For cleaning large mirrors Mr. Brashear recommends that, after being treated with nitric acid and potash, the surface be rubbed with prepared chalk until it is thoroughly clean and dry. It is then either washed

[1] It is a remarkable fact, which has probably been noticed by all who have had much silvering to do, that it is much more difficult to silver on a worked (*i.e.*, ground, polished) surface than on one from which the natural blown surface has not been removed.

again with water, or left dry as it comes from the chalk polishing until the silvering bath is ready.

When the surface is properly cleaned, the distilled water will wet and flow over the whole surface uniformly; if it is not, it will collect in drops on the plate. If it does this, the cleaning operations must be repeated.

It is essential that the utmost cleanliness be observed in all of these operations. They should be conducted preferably in glass or porcelain vessels, and the fingers should never be allowed to touch the surface which is to be silvered. If small, the plates are handled by means of

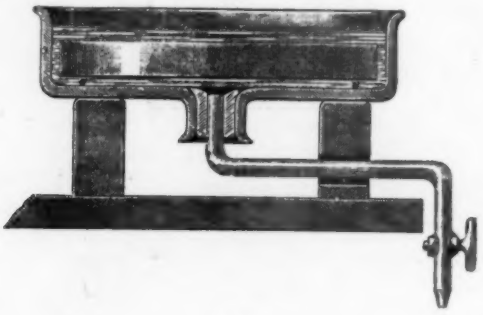


FIG. 4

glass tongs or supports like those shown in Fig. 2. If the plate is large it is necessary to use two of the latter, one on each side, or better to make a glass frame with two handles, similar to that shown in Fig. 3. For still larger mirrors, a glass dish with a stopcock in the bottom, from which the different washing fluids may be drawn in succession, may be used. The mirror is supported in this case by means of small glass rods which will permit of perfect washing. A shallow, stoppered bell glass is perhaps the most available commercial article. This is supported on two blocks of wood so as to lift the central stopper, into which the discharge tube is cemented by means of paraffine, away from its support. For the sake of economy the glass dish should of course be but very little larger than the mirror. (Fig. 4.) In case mirrors of irregular shapes are to be silvered, special dishes of just the right size may be made by roughly nailing together a box of wood of the required size and dimensions, and then thoroughly coating the inside with very hot melted paraffine. If the mirror be very large

indeed, the most convenient as well as the most economical way is to let the surface to be silvered itself be the bottom of the silvering dish, and form the sides by passing around the edges of the mirror a strip of paraffined paper, which is held in place by a rubber band or cord. The paper is cemented to the edge of the mirror by rapidly passing a hot iron around the latter. A shallow dish is thus formed, which serves to hold the cleaning and finally the silvering fluid. Or by using care the band may be put in place after cleaning, and used only for the silver bath, since it is only this that needs to be economized.

If the mirror is to be silvered face downward — a method preferred

FIG. 5

by some because less care is necessary during the silvering — some method of support must be adopted which will lift the face about a centimeter above the bottom of the silvering dish. In this case the method of support which I prefer, as more cleanly and less wasteful of space than any other, is the use of three wedge-shaped blocks of paraffined wood placed in the bottom of the silvering dish. When finished the mirror is removed by placing the hand covered with a sheet of blotting paper on the back, and then inverting the dish. If the mirror is too heavy to be held in one hand, both may be used while an assistant inverts the dish. Another method which I have never used, but which perhaps might be equally cleanly and efficient, would be the use of a suction clamp applied to the back of the mirror. (Fig. 5.)

To briefly recapitulate, the points essential to success in silvering are: (1) a thorough and systematic cleaning of the surface; (2) reasonably pure chemicals, and a silver-nitrate solution containing an excess

of silver; (3) uniformity of temperature between the silvering bath and the mirror, preferably from 15° to 20° C.; (4) the use of clean water, and plenty of it, in all the stages of operation, especially in the final washing.

The methods of operation described in this paper are probably most of them already familiar to those who have had experience in this work. It is not for them that this paper is written, but for those who, because of inexperience, have had difficulty in securing uniformly good results. If it is of any service in assisting them to a knowledge of a better method (and I certainly consider Mr. Brashear's method far superior for general use to the old Rochelle salts process), or of more convenient ways of working, the object of the author will have been accomplished.

F. L. O. WADSWORTH.

ON BRESTER'S VIEWS AS TO THE TRANQUILLITY OF THE SOLAR ATMOSPHERE.

IN the December (1894) number of *Astronomy and Astro-Physics* (p. 849) Mr. Brester has replied to certain criticisms of his Theory of the Sun which I had advanced in the number of the preceding August. A final word from me in reply to these remarks may, perhaps, be permitted.

To completely justify my objections it is only necessary, I think, to quote the words used by Mr. Brester ("A short Review of my Theory of the Sun," *Astronomy and Astro-Physics*, **13**, 218).

"The *interior tranquillity* of the Sun is not to be thought of merely as the *conditio sine qua non* of its permanent stratification, but as *a priori* much more probable than the ordinary theory of violent agitation. . . . . *A quiet interior* should, therefore, not surprise us. . . . . If, in general, solar phenomena teach us that the Sun is in a state of repose, and that this *quiet* is such that the Sun, in spite of its gaseous state, presents the *appearance of a solid.* . . ."

When one reflects that from purely physical considerations vertical movements in a stable atmosphere, either of a heavenly body or of our Earth, are not comparable with horizontal movements, one cannot speak of "a state of repose" of the Sun, if, as I have shown in the article referred to, storms of more than 100 meters a second accompany

the most ordinary phenomena on the Sun's surface — storms which exceed in violence by threefold our hurricanes. My objections seem, therefore, justified.[1]

Since Mr. Brester very naturally desires to dispose of my theory of the constitution of the Sun's atmosphere and the cause of the Sun-spots, I feel it necessary to reply briefly to his objections.

Mr. Brester seeks especially to disprove the existence of a very small density at the surface of the photosphere, and on the following grounds :

In the first place the radiation from different parts of the Sun's surface shows, according to Vogel's measures, a considerable increase of the general absorption towards the limb, an absorption which varies with the color. Seeliger has shown that this necessitates the assumption of a medium of high refractive power. I have myself alluded to this apparent inconsistency in my paper, "Ueber die Ursache der Sonnenflecken" (*Sitzber. der Wien. Ak. d. Wissensch.* p. 17, 1893). It finds, however, a ready explanation in the condition of the photosphere. A rare atmosphere in which flying particles are suspended fulfils the conditions of a highly refracting medium in the most complete manner.

The second objection brought forward by Mr. Brester, namely, that the great height of the Sun's atmosphere presupposes also a great density at the surface, no longer applies when one remembers that the atmosphere of a rotating heavenly body only reaches a limit at the point where centrifugal force equals that of gravity. A great extension of the atmosphere, even such as that of the Sun's atmosphere, denotes a high temperature at the surface and nothing more.

Mr. Brester refers also to the validity of Kirchhoff's law, which I have used in considering the glowing gas of the Sun's atmosphere, and cites in this connection certain researches on glowing gas; while Paschen somewhat later has been led to quite different results, proving the dependence of the light emission on temperature. The question is in any case an open one. But these researches have little significance for the glowing gas on the Sun, since under the high temperature which exists there all chemical action must be excluded. Kirchhoff's law is, as he himself has shown in his well-known memoir, a necessary deduction if the quality and intensity of the light rays

[1] I regret that in my paper, above referred to, I have by mistake interchanged the words "spherical" and "flattened" (p. 583).

depend only on the nature and temperature of the radiating body. The application of Kirchhoff's law seems, therefore, at all events admissible.

EGON VON OPPOLZER.

MUNICH, January, 1895.

The Variable Star 3416 S Velorum.—Professor Roberts explains his observations of this star (*A. J.*, No. 327) by supposing that the variable is a dark central star, with a brighter, but much smaller companion, revolving around it. The magnitude of the primary is $9^m.25$, of the companion about $8^m.05$. When the star is at a minimum, we have the light of the primary only, and the variable remains for over six hours at $9^m.25$. At a maximum we have the combined light of both stars, that is, $7^m.85$. It is, he says, much to be regretted that the star cannot be passed under the scrutiny of the spectroscope. Such an examination would yield a most valuable train of facts, and would raise probable results into actual knowledge. It is to be hoped that ere long we will have in the southern hemisphere a spectroscope so adapted, and so powerful, that in half a dozen nights we will have settled, without the prospect of a doubt, the motions of this peculiar binary system; and above all, the motions, relative masses, distances, and hence parallax of α_2 α_1 Centauri.

As a 24-inch photographic telescope, to be provided with both an object-glass prism and a slit spectroscope, has been offered by Mr. McClean to the Cape Observatory, and will presumably be accepted by the Government, the time when a powerful stellar spectroscope will be permanently established in the southern hemisphere is not far distant. Unfortunately, even such an instrument as this could hardly deal with the motion in the line of sight of an 8^m–9^m star.

J. E. K.

Reviews.

Étude sur le spectre de l'étoile variable δ Cephei. A. Bélopolsky. *Bulletin de l'Académie . . . de St. Petersbourg*, 1894. November, No. 3, pp. 267–306.

In *A. N.* **136,** 281 Bélopolsky announced that this star is subject to an orbital revolution, and stated the provisional results of the spectrographic observations of its motion in the line of sight. A translation of this article was published in the February number of this Journal (pp. 160, 161). The present memoir contains the observations thus far obtained, with a discussion of the resulting orbit.

For the very important purpose of investigating the spectra of variables which reach the sixth magnitude at minimum, a new spectrograph, with a compound prism, was constructed and attached to the 30-inch Pulkowa refractor. Under the best atmospheric conditions an exposure of an hour was sufficient to bring out the spectra of stars nearly as faint as the sixth magnitude. The portion of spectrum included was usually from about λ4500 to λ4300, the prism being adjusted for the rays at λ4410.

The comparison spectra employed were those of iron and hydrogen, the iron lines being impressed in about thirty seconds at the middle of the exposure, while the hydrogen light was thrown upon the slit at the beginning or end of the exposure. Unfortunately the $H\gamma$ line seemed, in some instances, to be displaced with reference to the iron lines, thus giving different results for the two comparison spectra; we shall refer again to this discrepancy.

Two methods of measuring the spectra were employed,—Vogel's first method, that of measuring relatively to a solar plate, and direct comparison with the iron lines at λ4405 and λ4415. The lines visible on each plate are enumerated in detail, with a description of their appearance. Two plates were obtained on most evenings of observation, and each was measured by the two methods.

The spectrum of δ Cephei is of Type IIa, but some lines which are narrow and faint in the Sun appear broad and strong in the star. No marked changes in the character of the spectrum were noted as

dependent upon the variation of the star's light, except, of course, the increased intensity of the spectrum at a time of maximum.

The star is a variable of short period ($5^d\ 8^h.8$), ranging from 3.7 mag. to 4.9 mag., but the maximum occurs $1^d14^h.6$, or only one-third of the period, after the minimum.

The velocities in the line of sight, based upon the displacement in respect to the iron lines, and reduced to the Sun, are given below, after reduction from units and tenths of the *lieue geographique* to the nearest half kilometer (1 *l. g.* = $5^{km}.56$):

Pulkowa M. T.			Velocity	Pulkowa M.T.			Velocity
	d	h	km		d	h	km
1894 Aug.	3	11.0	− 24.5	1894 Aug.	17	10.8	+ 0.5
	4	10.8	− 17.0		24	9.6	− 28.0
	5	11.0	− 22.5		25	9.9	− 18.5
	6	10.8	+ 4.0	Sept.	1	9.5	− 3.5
	8	10.6	− 22.0		3	9.4	− 27.0
	9	10.0	− 16.0		5	9.3	− 16.0
	12	10.7	− 11.0		6	9.2	− 6.5
	14	10.4	− 18.5		7	8.9	− 4.0
	16	10.4	− 10.0		11	9.0	− 9.5

The mean error of the measures is - - - $\pm 5^{km}.5$
The mean error for each day - - - - ± 3
The mean error of the deduced velocities - ± 3

It will be noted that the range in velocity is very much less than in the case of any of the spectroscopic binaries heretofore discovered, but it is quite too great to be due to errors of measurement.

The orbit is computed by the valuable method first proposed by Rambaut (*M. N.* **51**, 316–330), and more fully worked out by Lehmann-Filhés (*A. N.* **136**, 17–28). The period of revolution is taken to be the same as that of the star's variation. The velocity of translation of the system is found to be -14^{km} (approach). The other elements of the orbit are:

u_1 = 90°, the angle between the ascending node and the radius vector at the point where the sight-line component of the orbital velocity is 0.

ω = 88°, the angle between the ascending node and the perihelion (periastron).

e = 0.514, the eccentricity.

$lg\ \mu$ = 0.0678, the daily motion, in degrees = 67°.08.

$a \sin i = 990{,}000^{km}$ the projection of the semi-major axis.

i is not determinate, but in view of the probable eclipse it cannot be far from 90°.

T = 1.05 days after a minimum, is the time of periastron passage.

The major axis of the orbit evidently lies nearly in the line of sight, periastron being on the farther side from the Earth.

An ephemeris was computed from these elements, and it shows a fairly satisfactory accord with the observed velocities.

A curve is given exhibiting the variation in the velocity with the time, and also the light-curve of the star after Oudemans' observations. The two agree quite well, but the interval of 1.05 days between the time of minimum and the passage of the periastron is not explained. The ephemeris of the star's variation, taken from the *Annuaire du Bureau des Longitudes*, differs only very slightly from Chandler's elements, and is probably quite accurate.

In order to examine the relative displacement of the iron and hydrogen lines on certain of the plates, Bélopolsky has computed the velocities referred to the $H\gamma$ line and compared the results with the ephemeris, with less satisfactory results. His conclusion is that the $H\gamma$ line cannot in this case give as reliable determinations of velocity as the iron lines because usually it was imprinted on but one of the two spectrograms taken on a night, because it was too far away from the portion of spectrum used for measurement and was not the line for which the prism was set at minimum, and because the exposure to the hydrogen spectrum took place either at the beginning or end of the exposure to the star, and not at the middle time as in case of the iron spectrum. The discrepancy is an unfortunate one and necessarily diminishes our confidence in the accuracy of the results. It is to be expected that in future work with this instrument its stability will be increased, and the method of obtaining the comparison spectra be so modified as to obviate this uncertainty.

Of course the present observations form only a beginning of the researches which will be necessary to fully explain by orbital revolutions and eclipses the peculiar variations of the light of this star. The case is evidently much more complicated than that of the Algol variables, although perhaps simpler than that of β Lyræ.

F.

The Luminosity of Gases. III. A. SMITHELLS. *Phil. Mag.*, January, 1895.

THE second paper of this important series was noticed in *A. and A.* **13**, 587–588, 1894.

Of the present discussion the immediate subject is the various flame-spectra of copper oxides and chlorides, and of gold trichloride. One can here only hint at the method of study and at the results obtained.

The Bunsen burner, fitted with a sprayer, a "saturator" and a cone-separator, furnishes a luminous flame, which is then examined with a two-prism spectroscope. The observed spectra are mapped in the following very happy manner, *viz.*: the ruled scale is one of equal parts, but each division, instead of denoting an equal increment of wave-length, λ, denotes an equal increment of the value $\frac{1}{\lambda^2}$. The consequence is that the wave-length of each line is at once reducible to Ångström units, while the spectrum as a whole preserves its prismatic appearance, the lines at the blue end being crowded together.

As to results, the essentially new feature of this work is the discovery of the particular copper compound to which each of the various copper spectra are due.

Following are the author's conclusions as stated by himself:

"I. When cupric chloride is introduced into a flame, three substances are formed: metallic copper, cuprous chloride, and cuprous oxide. The first of these gives a bright yellow flame and a continuous spectrum; the second a bright blue tint and brilliant spectrum of bands and lines; the last a green tint and a spectrum of not very strongly developed bands. Under certain circumstances cupric chloride may exist in a flame, when it gives a feebly ruddy tint and a continuous spectrum.

"II. Gold chloride gives a flame-spectrum only in presence of an excess of chlorine or of hydrochloric acid and oxygen.

"III. In the above cases the development of a spectrum is concomitant with chemical changes affecting the substance concerned; a fact in harmony with the view as to the origin of flame-spectra advocated by Pringsheim."

The evidence which Professor Smithells adduces for each of the above statements is direct and clear; but at the same time it is more

than likely that many of his readers will refuse to admit that his evidence is conclusive. To illustrate, one is not quite certain that the products which condense on the outside of a vessel of cold water held in a flame are exactly the compounds which exist *in the flame* and give it luminosity.

Concerning the subject of luminosity in general, and the Bunsen flame in particular, this paper only confirms a growing suspicion that one has here to deal with a vastly more complicated piece of mechanism than has hitherto generally been supposed; and one is driven to wish that the problem might be attacked by the photographic method and large dispersion. H. C.

Popular Scientific Lectures. ERNST MACH, Professor of Physics in the University of Prague. Translated by THOMAS T. MCCORMACK. (Open Court Publishing Co., Chicago, 1895.)

The production of a popular scientific lecture of the highest order is to be reckoned among the later achievements of a profound scholar. The task requires a breadth of interest which the specialist has sometimes lost early in his career; it requires also a style which is lucid without the introduction of tedious detail, a style which is accurate without dependence upon formulæ. These demands are thoroughly satisfied in the volume before us. The lectures are not so strikingly original as some of Maxwell's nor so profound as those of Kelvin; but they are truly remarkable in the insight they give into the relationship of the various fields cultivated under the name of Physics, and the book cannot fail to hold the attention of every reader who is interested in the history of the *development* of Physics.

The twelve lectures chosen for translation cover the most diverse fields. Among them is one on "Forms of Liquids," one on the "Velocity of Light," one on the "Fundamental Concepts of Electrostatics." But perhaps the most valuable is that on the "Principle of the Conservation of Energy." The rise of this idea is traced in the history of mechanics, heat and electricity. The unity of these subjects is particularly emphasized by a happy guess as to what might have been the result upon our electrical ideas had Riess devised his thermo-electrometer before Coulomb used his electrostatic balance. The chapter on the "Economical Nature of Physics" contains a discussion of the question as to what is meant by "a physical explanation," following in

thought the now famous definition of Mechanics which Kirchhoff has given. One is apt to imagine now and then that the author is treading dangerously near metaphysical ground; but the chances are that the reader will find, very shortly, that the only metaphysics involved is that which has crept into his own everyday thinking. A vein of humor is met here and there reminding the reader of Heaviside, never offending one's taste. These features, together with the lightness of touch with which Mr. McCormack has rendered them, make the volume one that may be fairly called rare. The spirit of the author is preserved in such attractive, really delightful, English that one is assured nothing has been lost by translation. H. C.

The Source and Mode of Solar Energy throughout the Universe. I. W. HEYSINGER, M.A., M.D. (J. B. Lippincott & Co., Philadelphia, 1895.)

THIS book must be relegated to the paradox shelf, although many parts of it are well written, many of its statements are true, and it is printed and bound in an excellent manner by a prominent publishing house. Its author evidently has a considerable acquaintance with popular scientific literature, and the facility with which well-known authorities are quoted in apparent support of heretical views, together with the attractive appearance just referred to, make the book a dangerous one to the general reader.

The author weighs the various theories which have been advanced to account for the maintenance of solar energy, and finds them all wanting; he then proceeds to unfold a theory of his own. He is struck by the circumstance that free oxygen exists in the atmospheres of the Earth and other planets, but no free hydrogen, while in the atmosphere of the Sun there is free hydrogen but no oxygen. (He mistakes the absence of oxygen lines from the solar spectrum for proof that oxygen does not exist in the Sun.) This is for him the main fact to be considered in any explanation of solar phenomena. The suggestion that the hydrogen molecules escape from the planetary atmospheres by virtue of their high velocity is dismissed in a few words, as unworthy of serious consideration. Some agent is needed which will liberate oxygen in the atmospheres of the planets, and hydrogen in the atmosphere of the Sun, accompanied, in the latter case, by the production of light and

heat. It is needless to say that this agent is electricity. Space is filled with attenuated aqueous vapor, the conductivity of which is doubtless increased by the presence of other gases. By the rotation of the planets powerful electric currents are generated, which, passing in currents to the Sun, liberate hydrogen there by electrolytic action, the oxygen remaining on the planets. No sun can therefore exist without at least one planet; each is the opposite and necessary complement of the other, and thus is established the dual relation, exemplified in the sexes, so dear to the heart of the paradoxer.

The source of solar energy is after all not very clear, since the author objects strenuously to the supposition that the axial rotation of the planets is in any way affected. This is the more remarkable since the contradiction of the principle of the conservation of energy in Siemen's hypothesis is clearly pointed out. In the long explanation of this subject in chapter IV the meaning is lost in words; but the idea seems to be that the true source of solar energy is the "potential energy of space," which is inexhaustible, and which is made active by the rotation of the planets, while rotation is an inherent property of matter, or rather, its persistence in the case of the planets, under the circumstances considered by the theory, no more requires explanation than its original existence. It is needless to follow the detailed application of the theory to the various phenomena of the solar system, which it explains in a manner satisfactory to the author. J. E. K.

Recent Publications.

A list of the titles of recent publications on astrophysical and allied subjects will be printed in each number of The Astrophysical Journal. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. The Sun.

Evershed, J. The Electric Origin of the Solar Chromosphere. Knowl. **18**, 39, February, 1895.

Howlett, Rev. F. Remarks on Three Volumes of Sun Spot Drawings presented to the Society. M. N. **55**, 73, 1894.

Quimby, A. W. Sun Spot Observations. A. J. No. 334, **14**, 175.

Tacchini, P. Résumé des observations solaires, faites à l'observatoire Royal du Collége Romain pendant les 2e, 3e et 4e trimestres, 1894. C. R. **120**, 143–144.

Tacchini, P. and Riccò, A. Immagini spettroscopiche del bordo solare osservate a Roma e Catania nei mesi di novembre e dicembre del 1893. (Plate) Mem. Spettr. Ital. **23**, November, 1894.

3. Stars and Stellar Photometry.

Backhouse, T. W. Variable Orange Stars. Obs'y **18**, 94, January, 1895.

De Ball, L. Anzeige eines neuen veränderlichen Sterns BD.—6°.5416 in Aquila. A. N. **137**, 73–74.

Bélopolsky, A. Étude sur le spectre de l'étoile variable δ Cephei. Bul. l'Acad. Imp. de Sci. St. Petersburg, 267–306, November, 1894.

Deslandres, H. Sur la vitesse radeale de ζ Hercule. C. R. **120**, 1252.

Fleming, M. Stars Having Peculiar Spectra. A. N. **137**, 71–74.

Maunder, E. W. Dark "Lanes" of the Milky Way. Knowl. **18**, 36–38, February, 1895.

Sawyer, Edwin F. On the Light-Variations of 7149 S Sagittæ. A. J. No. 336, **14**, 189–191.

Tisserand, F. Sur l'étoile variable β de Persei (Algol). C. R. **120**, 125–130.

Yendell, Paul S. On the Variable Star 103 T Andromedæ. A. J. No. 335, **14**, 183–184.

5. PLANETS, SATELLITES AND THEIR SPECTRA.

BRENNER, L. Mars-Beobachtungen an der Manora-Sternwarte vor der Opposition 1894. A. N. **137**, 49–62.

ELGER, T. G. Selenographical Notes. Obs'y **18**, 85–86, January, 1895.

GROSSMANN, E. Beobachtungen des Mondkraters Mösting A und der Mondsterne. A. N. **137**, 113–128.

JOHNSON, CHARLES W. L. Pseudo-Satellites of Jupiter in the Seventeenth Century. Nat. **51**, 285–286.

MEUNIER, S. Recherches sur les conditions qui ont déterminé les caractères principaux de la surface lunaire. C. R. **120**, 225–227.

PRINZ, W. Le nouveau cratère près de Chladni et la limite de definition des photographies lunaires actuelles. A. N. **137**, 91–92.

SCHIAPARELLI, G. Alcune mutazione importanti osservate nella superficie di Marte. A. N. **137**, 97–100.

SCHIAPARELLI, G. Sulle maree prodotte in un pianeta od in un satellite dall'azione del suo corpo centrale. Atti. dell' I. R. Accademia degli Agiati, 1894, 11 pp.

6. COMETS, METEORS AND THEIR SPECTRA.

DENNING, W. F. Meteors of 1895, January 1. Obs'y **18**, 93-94, January, 1895.

8. TERRESTRIAL PHYSICS.

BAUER, L. A. Beiträge zur Kenntniss des Wesens der Säcular-Variation des Erdmagnetismus. Mayer & Müller, Berlin, 1895, 54 pp.

HERSCHEL, A. S. Aurora of November 23, 1894. Nat. **51**, 246–247.

KITTO, E. Report of Magnetical Observations at Falmouth Observatory for the Year 1893. Proc. R. S. **56**, 557–563.

MÜLLER, P. J. Erdmagnetismus und Luftelektrizität. Him. u. Erde. **7**, 153–167, 1895.

MOUREAUX, Th. Sur la valeur absolue des éléments magnétiques au 1er janvier, 1895. C. R. **120**, 42–43.

9. EXPERIMENTAL AND THEORETICAL PHYSICS.

EDER, J. M. und VALENTA, E. Absorptionsspectren von farblosen und gefärbten Gläsern mit Berücksichtigung des Ultraviolett. Denkschr. d. Wiener Akad. **61**, 11 pp.

FOUSSEREAU, G. Sur l'entrainement des ondes lumineuses par la matière en mouvement. C. R. **120**, 85–88.

GUILLAUME, CH. ED. Application du principe de Doppler à l'énergie des radiations. Jour. de Phys. **4** (3^{me} sér.) 24–29, January, 1895.

OLSZEWESKI, K. The Liquefaction and Solidification of Argon. Chem News, **71**, 59–60.

THOMSON, J. J. Electric Discharge through Gases. Nat. **51**, 330–333.

10. THE SPECTRA OF THE ELEMENTS.

CROOKES, W. On the Spectra of Argon. (Abstract.) Chem. News, **71**, 58–59.

EDER, J. M. und VALENTA, E. Ueber die verschiedenen Spectren des Quecksilbers. Denkschr. d. Wiener Akad, **61**, 30 pp.

EDER, J. M. und VALENTA, E. Ueber das Spectrum des Kaliums, Natriums und Cadmiums bei verschiedenen Temperaturen. Denkschr. d. Wiener Akad. **61**, 20 pp.

EWAN, T. On the Absorption Spectra of Dilute Solutions. Proc. R. S. **57**, 117–161.

11. PHOTOGRAPHY.

BONACINI, C. La cromofotografia interferenziale e un nuovo caso di sensibilità pei colori. Mem. Spettr. Ital. **23**, 146–154, 1894.

AUGUSTE et LOUIS LUMIÈRE. Sur les développateurs organiques de l'image latente photographique. Ann. Chim. et Phys. **4** (7 me sér.) 271–288, January, 1895.

12. INSTRUMENTS AND APPARATUS.

SCHUSTER, ARTHUR. Electrical Notes. Phil. Mag. February, 1895.

TURNER, H. H. Note on the Geometrical Optics of the Skew Cassegrain. Obs'y **18**, 81–83, January, 1895.

13. GENERAL ARTICLES, MEMOIRS AND SERIAL PUBLICATIONS.

LARMOR, J. The Significance of Wiener's Localization of the Photographic Action of Stationary Light Waves. Phil. Mag. January, 1895.

MONCK, W. H. S. The Structure of the Universe. Knowl. **18**, 38, February, 1895.

PRESTON, S. CHARLES. Comparative Review of Some Dynamical Theories of Gravitation. Phil. Mag. February, 1895.

RAYLEIGH, LORD and RAMSAY, W. Argon: A new Constituent of the Atmosphere. (Abstract.) Chem. News, **71**, 51–58.

ROWLAND. Modern Theories as to Electricity. Engineering Mag. January, 1895.

TUTTON, A. E. A New Element in the Nitrogen Group. Nat. **51**, 258.